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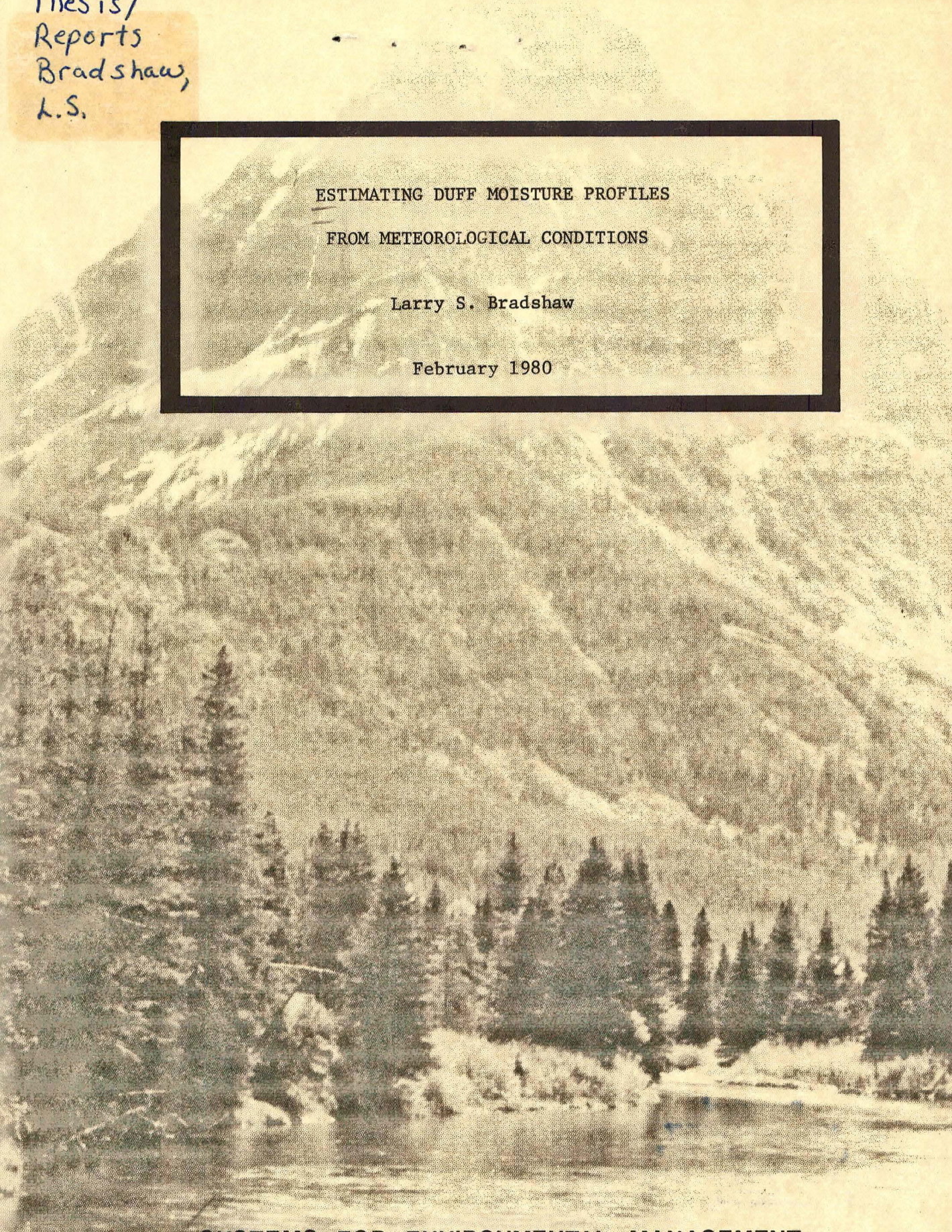
ESTIMATING DUFF MOISTURE PROFILES FROM METEOROLOGICAL CONDITIONS

Larry S. Bradshaw

February 1980



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Estimating Duff Moisture Profiles from Meteorological Conditions

SUBMITTED BY

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SUBMITTED TO

FIRE IN MULTIPLE USE MANAGEMENT RD&A PROGRAM
NORTHERN FOREST FIRE LABORATORY
INTERMOUNTAIN FOREST & RANGE EXPERIMENT STATION
USDA FOREST SERVICE
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EW

Estimating Duff Moisture Profiles from Meteorological Conditions

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PREFACE

"Estimating Duff Moisture Profiles" is the final report submitted under Supplement No. 7, Master Memorandum 12-11-204-153, effective 2 August 1977, between Systems for Environmental Management, Missoula, Montana, and the Intermountain Forest and Range Experiment Station, Ogden, Utah. The study was performed under cooperative aid agreement between Systems for Environmental Management and the Fire in Multiple Use Management RD&A Program, Northern Forest Fire Laboratory, Missoula, Montana, under authority 16 USC 581, 581a - 581i. Systems for Environmental Management is a Montana nonprofit research and educational corporation cooperating with land management agencies in the interest of improved environmental management.

ACKNOWLEDGEMENTS

This was truly a cooperative aid agreement. Many thanks to the following scientists: from the USDA-Forest Service, Dr. Michael Fosberg, from the Riverside Fire Laboratory; Bill Frandsen, Bill Fischer, Arnold Finklin, Pat Hartless and Michael Hartkorn from the Northern Forest Fire Laboratory; to Collin Bevins, Systems for Environmental Management; John Roberts of the Lolo National Forest; finally, to Dr. James Lotan, Program Manager, Northern Forest Fire Laboratory.

TABLE OF CONTENTS

Preface ---------- i

Acknowledgements ---------- ii

Table of Contents ---------- iii

Study Problem ---------- 1

Objectives and Methods ---------- 2

Field Sampling Results ---------- 7

Model Validation ---------- 23

Discussion ---------- 33

Literature Cited ---------- 35

Appendix A: Program DUFF Use Instructions ---------- 38

Appendix B: Program DUFF Documentation and Flowchart ---- 44

Appendix C: Field Study Plan ---------- 60

STUDY PROBLEM

Moisture contents of duff and litter horizons of forest floors are recognized as influential factors in prescribed fire behavior and effects, and in estimating lightning fire ignition probabilities (Norum, 1977; Fuquay et. al., 1979). Several studies exist documenting diverse effects of prescribed fire as used in multiple land or fire management objectives (Biswell and Schultz, 1957; Van Wagner, 1963; Albini, 1975; Norum, 1976; Miller, 1977, etc.).

During the last ten years, several attempts have been made to 'model' or predict duff and litter moisture contents form various environmental and/or synthetic parameters. Regressions based on computed moisture or drought indices (Jarvis and Tuck, 1968; Johnson, 1968; Muraro and Lawson, 1970) correlated the various indices to duff and litter moisture contents at site specific locations. Van Wagner (1970) developed a theoretically-based mathematical model to predict moisture contents of duff and litter horizons with constant boundary conditions--a condition rarely found in forested areas.

Concurrently, investigations of the wetting and drying processes and rates of woody fuels in forest environements as a basis for predicting moisture contents were being conducted. Probably the most noted work in the field has been conducted by Research Meteorologist Dr. Michael Fosberg. His extensive research (Fosberg, 1970; 1971a; 1971b; 1972;

Fosberg and Deeming, 1971; Fosberg et. al., 1970a; 1970b) has been incorporated into the National Fire Danger Rating System (Deeming et. al. 1974).

More recently, Fosberg (1975; 1977) developed a theoretically-based, variable boundary condition model to predict moisture contents of the duff and litter horizon. Implementation of Fosberg's model has been impeded by two factors. First, the model was in manuscript form only and unavailable for active fire management processes. Second, model predictions have been calibrated by laboratory experiments only, without consideration of rainfall infiltration, and field verification of its predictions are nonexistent. The task addressed by this study is to program, test and calibrate the theoretical model developed by Dr. Fosberg.

STUDY OBJECTIVES

1. To produce an operational computer program to define and display the frequency of occurrence of duff moisture conditions important for the planning or prescribed burning operations.
2. To develop, analyze, validate, and implement an on-site duff moisture content prediction model suitable for activity-level prescribed fire planning and scheduling.

METHODS

In response to the first objective, Collin Bevins and myself from SEM, along with Bill Fransden from RWU 2103, met with Dr. Fosberg in early September, 1978. Program DUFF was then written with algorithms for estimating precipatory effects in the litter and duff horizons

included. Instructions for using program DUFF are detailed in Appendix A. A flowchart and documentation of program DUFF are found in Appendix B. A listing of program DUFF is included in a separate appendix, along with support documentation for statistics and simulation runs. DUFF was then rewritten in subroutine format, capable of accepting meteorological information from the National Fire Weather Library (Furman and Brink, 1975) and included in programs RXWTHR and RXBURN (Bradshaw and Fisher, 1980). Programs RXWTHR and RXBURN are programs that display frequency of occurrence and co-occurrence of various factors important in planning and executing prescribed fires.

A very brief description of model processes and parameters follows. Appendix B and Fosberg (1975) allow more detailed examination.

The model considers the physical properties and arrangements of particles making up uniform layers of a litter and duff horizon, bounded below by a thick stable boundary (sink) layer and above by variable atmospheric conditions. Moisture content is computed from temperature and vapor density of void spaces within a layer.

Each layer changes in response to surface temperature and relative humidity changes at a rate limited by void-to-particle and particle-to-void diffusivities. Changes in surface boundary conditions are transported down through the layers in an iterative process. The upper boundary conditions for the surface layer are atmospheric conditions; upper boundary conditions of the second layer are first layer conditions as modified by surface conditions. These changes are iteratively transferred through each layer to the bottom layer, which acts as a heat

and moisture sink. Temperature and vapor density changes through the layers are defined by the exponential exchange functions:

$$T_t = T_{t-1} + (1 - \zeta_T * e^{(-\delta t/\tau_{TB})}) * (T_o - T_{t-1}) \text{ ; and}$$

$$\rho_t = \rho_{t-1} + (1 - \zeta_M * e^{(-\delta t/\tau_{MB})}) * (\rho_o - \rho_{t-1}) \text{ ; respectively,}$$

where:

T_t = New temperature of layer (deg k)

T_{t-1} = Temperature of layer at last time increment

T_o = Boundary layer temperature

ρ_t = New vapor density of layer (gm/cm^3)

ρ_{t-1} = Vapor density at last time increment

ρ_o = Boundary layer vapor density

δt = Simulation timestep (t - (t-1)), sec

ζ_T = Temperature homogeneity coefficient (dimensionless)

ζ_M = Moisture homogeneity coefficient (dimensionless)

τ_{TB} = Layer temperature timelag (sec)

= f(layer thickness; porosity; thermal diffusivity; particle temperature timelag; particle density; and bulk density)

τ_{MB} = Layer moisture timelag (sec)

= f(layer thickness; porosity; vapor diffusivity; particle moisture timelag; particle density; and bulk density)

Layer saturation vapor pressure (e_s) is then calculated from the layer temperature; from the equation of state ($e = \rho RT$) actual vapor pressure (e) is calculated; and the ratio ($100*e/e_s$) defines the relative humidity of void spaces in the layer.

Equilibrium moisture content of particles is then computed by using temperature and relative humidity as independant variables in Wood Products Laboratory regression equations. These are the same functions used in NFDRS 1- and 10- hour fuel moisture calculations.

The coefficients ζ_T and ζ_M calibrate the exchange functions. For theoretical solutions, they have values of 1; in field situations, they have values of less than one.

Estimating precipitation effects considers two factors. The first is adsorption (or desorption) of water by particles in a saturated environment. Particles adsorb free water at a rate of 2-15 percent per hour, stress dependent (Fosberg, personal communication). An exponential function controls the rate of change in particle moisture content, as a function of the ratio of emc to particle saturation.

The second consideration is free water percolating through void spaces in each layer. The amount of free water in the voids (volumetric moisture content--$\frac{\text{cc } H_2O}{\text{cc void}}$) is determined by solving a third degree polynomial. The equation is a function of rainfall rate (cm/sec); the layer's hydraulic conductivity (cm/sec); and porosity.

The moisture content is then determined by summing the moisture contents of supersaturated particles with the volumetric moisture contents of the voids for each layer.

After the end of a period of rainfall, water in voids percolates through, and layer particles lose moisture at a rate of 2-15%/hour to the fiber saturation level, at which point, solutions return to the normal exponential rate, as defined above.

Hydraulic conductivities of duff and litter horizons are suffi-

ciently high (up to 30 cm/sec) such that puddling of water need not be considered except in layers below the duff (Fosberg, 1978). For example, a high rainfall rate of one inch per hour yields a flux of 7×10^{-4} cm/sec.

In response to the second objective, William Frandsen (RWU-2103) and Bill Fischer (RWU-2108) developed a summer field project providing the framework and data-base for on site model validation. A copy of the study plan for field work is included in Appendix C, and is briefly summarized here.

Duff moistures were sampled at four sites (1, 2, 3, 4) on an elevation gradient along the Elk Meadow Road west of Missoula. Three samples were taken once a day at each site, approximately biweekly from August 1979 through 18 October 1979. One day at each site, three samples were taken every two hours over a twenty-four hour period. At site 4, twenty-four hour analysis included period with rainfall.

Each site had continuously recording weather stations, monitoring temperature, relative humidity and precipitation during the course of the study. This information was then used for providing surface boundary conditions in model verification work.

Duff samples were randomly sampled from a one hundred square foot area at each site. The depths and moisture content of the upper and lower horizons were measured and recorded for each of the three samples. Also, a temperature profile was taken at each sample point. Temperatures were recorded at the ground surface, and at depths of one, two, three, and four centimeters.

FIELD SAMPLING RESULTS

Samples were taken according to the scheduling shown in Table 1. Site 1 was generally sampled first, with Site 4 last. Median sampling hours were 0915, 1010, 1100, and 1300 for sites 1, 2, 3, and 4, respectively.

General site moisture statistics are given in Table 2. Site 4, the higher elevation site, was the wettest, despite a sampling time of almost four hours later in the day than Site 1. The driest site was Site 2, followed by Sites 3 and 1. Daily mean moisture contents (average of three samples), and the range of moisture content are displayed in Figures 1-4, for Sites 1-4, respectively. Mean traces and ranges from 24-hour samples are displayed in Figures 5-8, for Sites 1-4 respectively. All sites had high variances. Analyses of variances of both site-to-site differences on the same day, and sample-to-sample variances at the same site on the same day showed that each site belongs to a statistically distinct ($p < 0.05$) population. It was noted that as moisture content increased, so does the variance. This is especially evident for sample days 3 and 9 at all sites.

Frequency distributions of lower duff depths are displayed in Figures 9-12 for Sites 1-4 respectively. Each distribution was broken down into four groups, and an average depth for each group computed. These grouping of duff depths at each site were then used to obtain a distribution of moisture contents at each site in model verification work. Upper duff depths were narrowly distibuted between .25 and 2.00 centimeters, with an enormous number at .25 centimeters. The average value of .30 centimeters was used as upper layer depth at each site.

Table 1: Sample Days, Dates and Times

	Site 1		Site 2		Site 3		Site 4	
Sample Day	Date	Time	Date	Time	Date	Time	Date	Time
1	8/7	1145	8/7	1350	8/7	1500	8/7	1610
2	8/9	1015	8/9	1120	8/9	1300	8/9	1345
3	8/13	1040	8/13	1430	8/13	----	8/13	1315
4	8/14	----	8/14	0945	8/14	0900	8/14	----
5	8/16	0900	8/16	0945	8/14	1035	8/16	1135
6	8/20	0915	8/20	1015	8/20	1120	8/20	1250
7	8/23	0915	8/23	1000	8/23	1045	8/23	----
8	8/27	0910	8/27	1025	8/27	1130	8/27	1315
9	8/30	0915	8/30	1045	8/30	1130	8/30	1305
10	9/6	0910	9/6	1020	9/6	1130	9/6	1300
11	9/10	0900	9/10	0950	9/10	1030	9/10	1130
12	9/13	0910	9/13	1010	9/13	1110	9/13	1350
13	9/17	0855	9/17	0945	9/17	1030	9/17	1120
14	9/20	0850	9/20	0945	9/20	1030	9/20	1115
15	9/24	0900	9/24	0950	9/24	1040	9/24	1115
16	9/27	0900	9/27	1000	9/27	1045	9/27	1130
17	10/1	0925	10/1	1015	10/1	1050	10/1	1140
18	10/4	0910	10/4	1010	10/4	1100	10/4	1150
19	10/9	1015	10/9	1055	10/9	1130	10/9	1250
20	10/11	0915	10/11	1010	10/11	1100	10/11	1150
21	10/18	0905	10/18	1010	10/18	1100	10/18	1235
Median sample time		0915		1010		1100		1300

Table 2: Site Moisture Summaries

	number	mean %	mode %	median %	std. dev %	range %	variance
Site 1							
upper	60	52	23	28	52	14-270	2723
lower	60	73	51	52	50	9-204	2522
Site 2							
upper	63	50	13	20	50	8-175	2481
lower	63	49	23	25	41	15-141	1652
Site 3							
upper	60	51	12	19	54	10-216	2967
lower	60	62	18	31	57	14-232	3207
Site 4							
upper	57	59	16	22	63	11-234	3984
lower	57	71	34	45	55	22-241	3060

Figure 1:

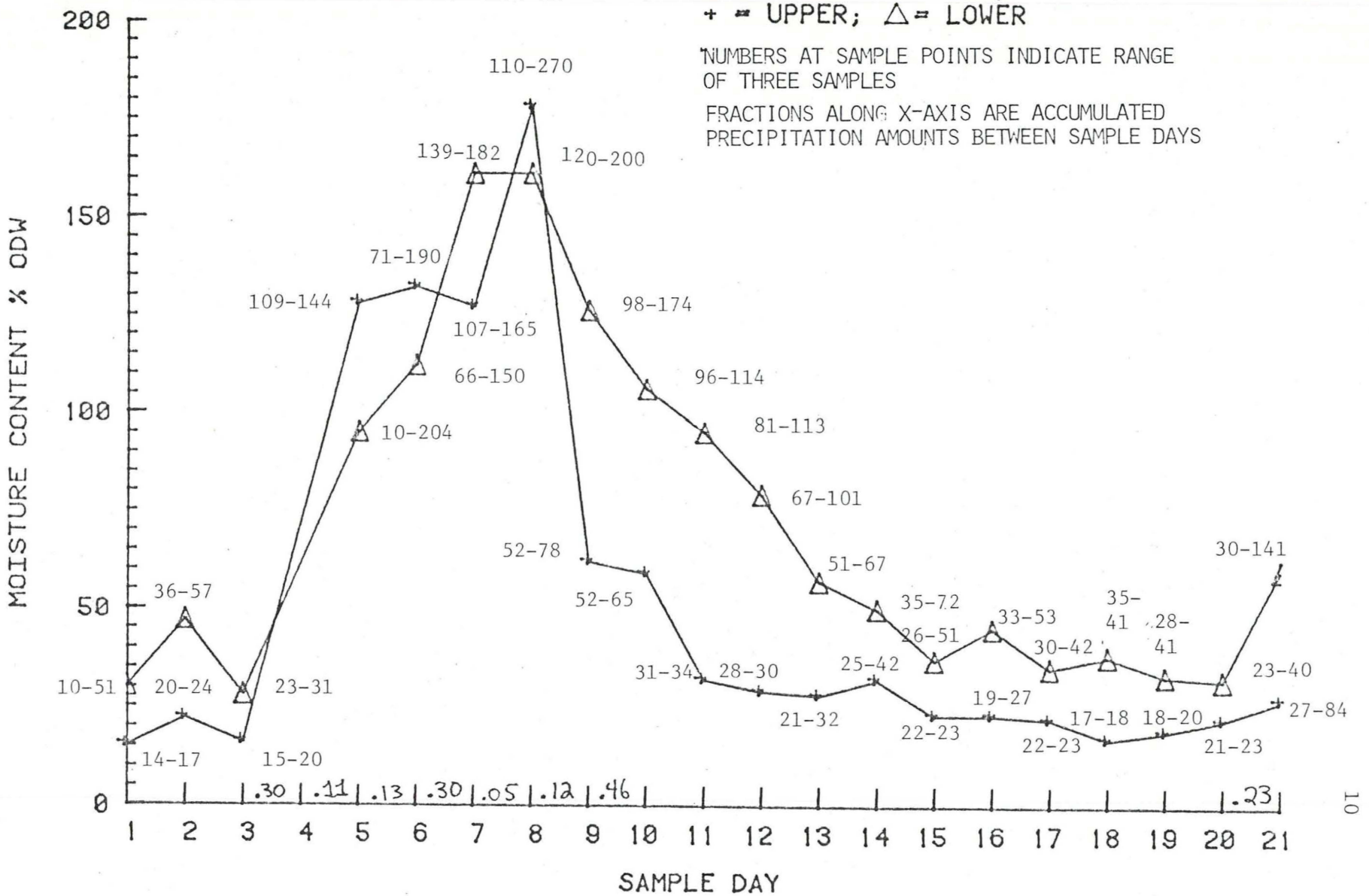

MEAN DUFF MOISTURE, SITE 1
+ = UPPER; △ = LOWER
NUMBERS AT SAMPLE POINTS INDICATE RANGE OF THREE SAMPLES
FRACTIONS ALONG X-AXIS ARE ACCUMULATED PRECIPITATION AMOUNTS BETWEEN SAMPLE DAYS
MOISTURE CONTENT % ODW
SAMPLE DAY
200
150
100
50
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
.30 .11 .13 .30 .05 .12 .46 .23
10-51
20-24
23-31
14-17
15-20
36-57
109-144
71-190
107-165
139-182
110-270
120-200
66-150
10-204
98-174
96-114
81-113
67-101
52-78
52-65
51-67
35-72
26-51
31-34
28-30
21-32
25-42
22-23
33-53
19-27
30-42
17-18
22-23
35-41
28-41
18-20
21-23
30-141
23-40
27-84

Figure 2:

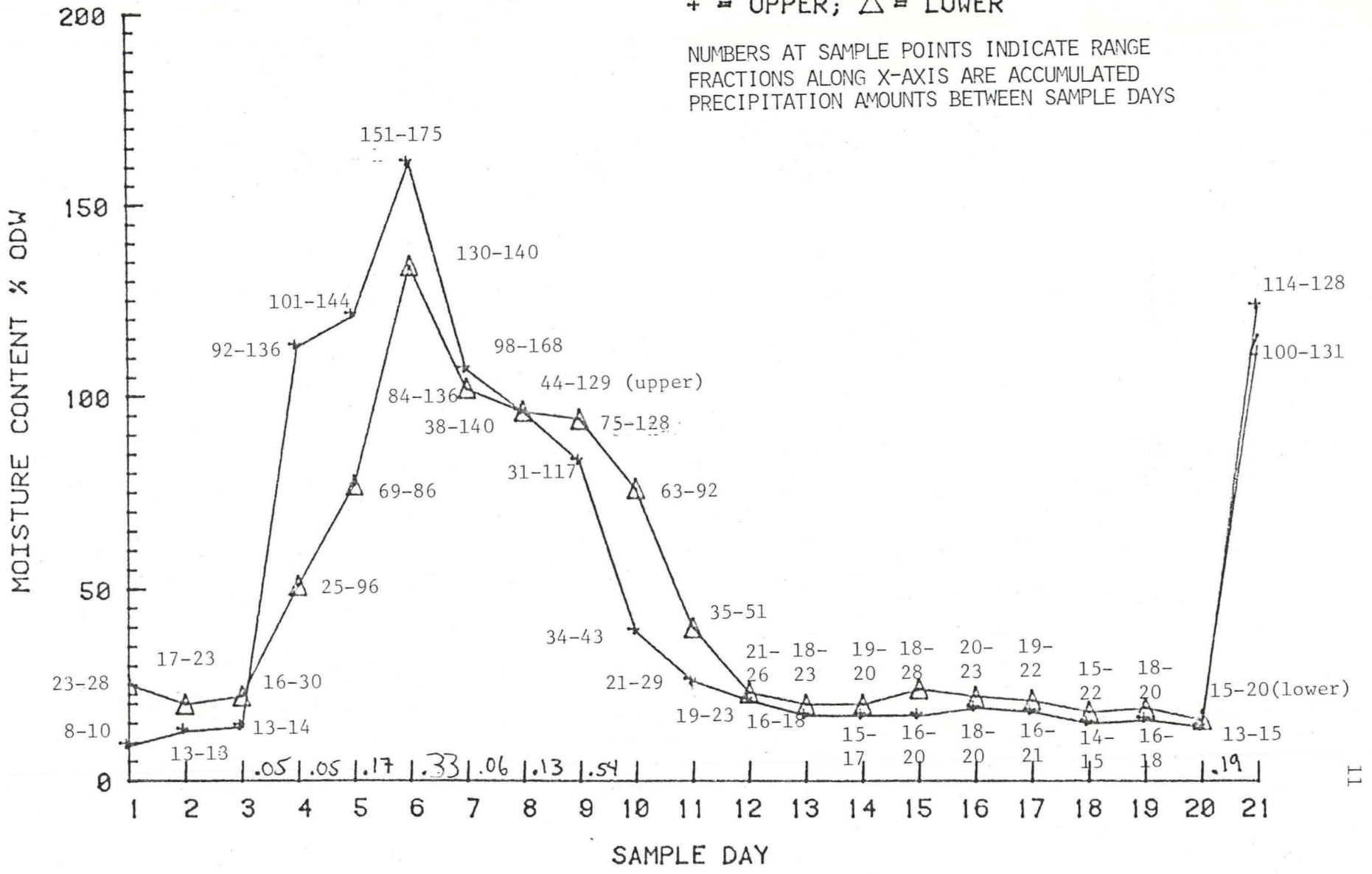

MEAN DUFF MOISTURE, SITE 2
+ = UPPER; △ = LOWER
NUMBERS AT SAMPLE POINTS INDICATE RANGE
FRACTIONS ALONG X-AXIS ARE ACCUMULATED
PRECIPITATION AMOUNTS BETWEEN SAMPLE DAYS
MOISTURE CONTENT % ODW
SAMPLE DAY
200
150
100
50
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
151-175
130-140
101-144
92-136
98-168
44-129 (upper)
84-136
38-140
75-128
31-117
69-86
63-92
25-96
35-51
34-43
17-23
23-28
16-30
21-29
8-10
13-14
19-23
13-13
16-18
114-128
100-131
15-20(lower)
13-15
21-26
18-23
19-20
18-28
20-23
19-22
15-22
18-20
15-17
16-20
18-20
16-21
14-15
16-18
.05 .05 .17 .33 .06 .13 .54 .19

Figure 3: MEAN DUFF MOISTURE, SITE 3

+ = UPPER; △ = LOWER

NUMBERS AT SAMPLE POINTS INDICATE RANGE

FRACTIONS ALONG X-AXIS ARE ACCUMULATED PRECIPITATION AMOUNTS BETWEEN SAMPLE DAYS

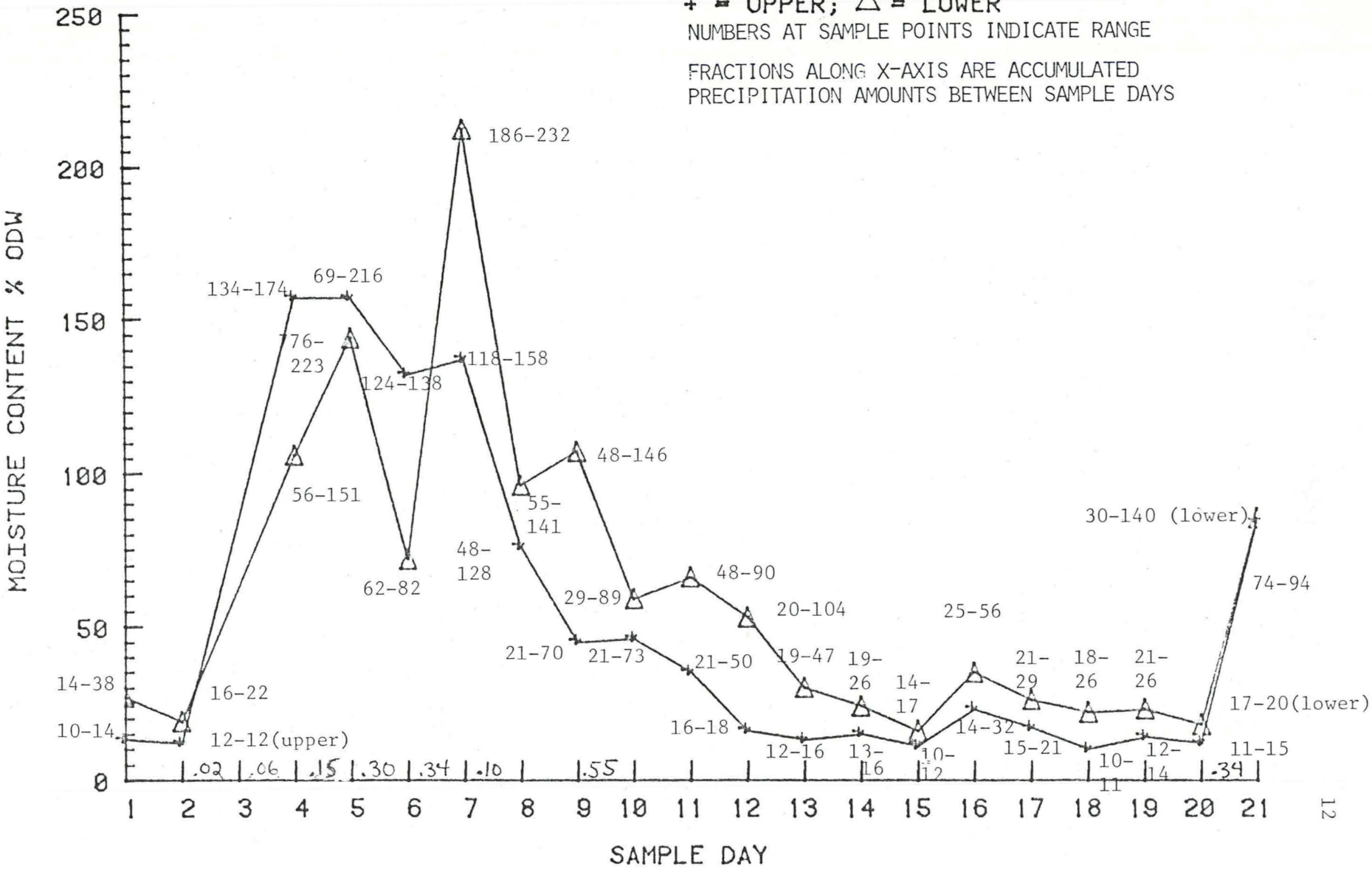


Figure 4: MEAN DUFF MOISTURE, SITE 4
+ = UPPER; △ = LOWER
NUMBERS AT SAMPLE POINTS INDICATE RANGE
FRACTIONS ALONG X-AXIS ARE ACCUMULATED PRECIPITATION AMOUNTS BEWEEN SAMPLE DAYS

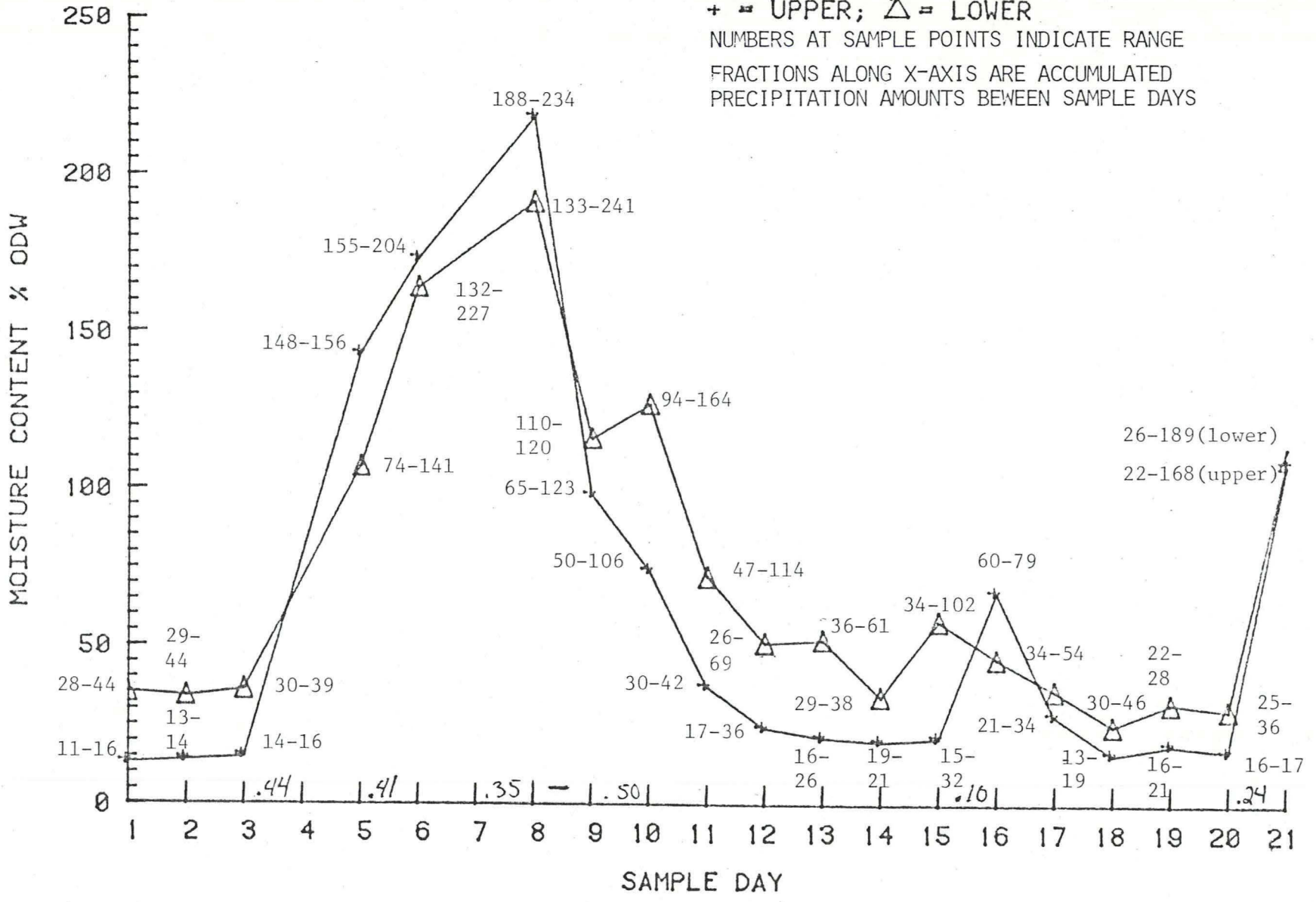


Figure 5:

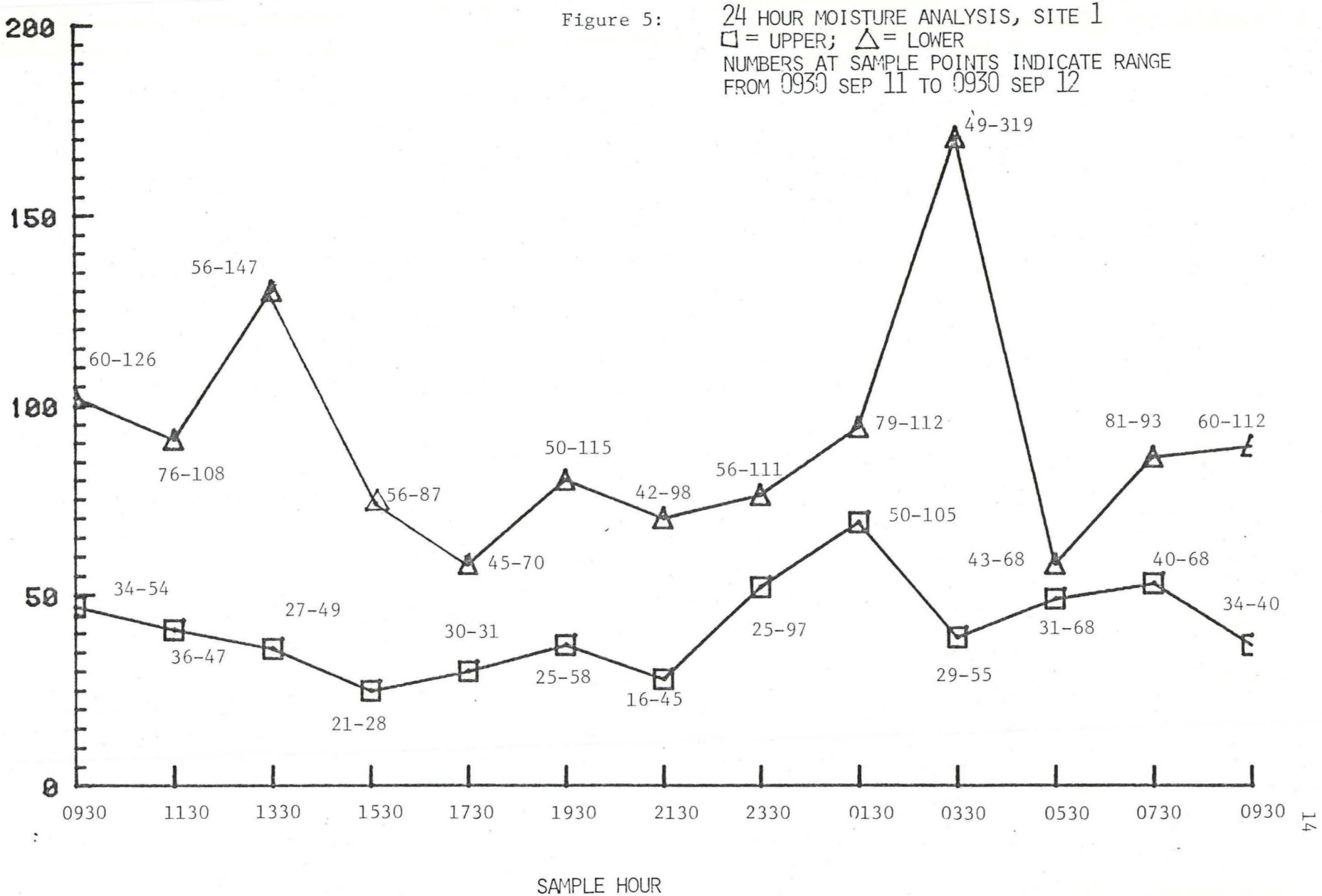

24 HOUR MOISTURE ANALYSIS, SITE 1
□ = UPPER; △ = LOWER
NUMBERS AT SAMPLE POINTS INDICATE RANGE
FROM 0930 SEP 11 TO 0930 SEP 12
200
150
100
50
0
60-126
76-108
56-147
56-87
45-70
50-115
42-98
56-111
79-112
49-319
43-68
50-105
29-55
31-68
81-93
60-112
40-68
34-40
34-54
36-47
27-49
21-28
30-31
25-58
16-45
25-97
0930
1130
1330
1530
1730
1930
2130
2330
0130
0330
0530
0730
0930
SAMPLE HOUR

Figure 6: 24 HOUR MOISTURE ANALYSIS, SITE 2
FROM 0900 SEP 4 TO 0900 SEP 5
+ = UPPER; △ = LOWER
NUMBERS AT SAMPLE POINTS INDICATE RANGE

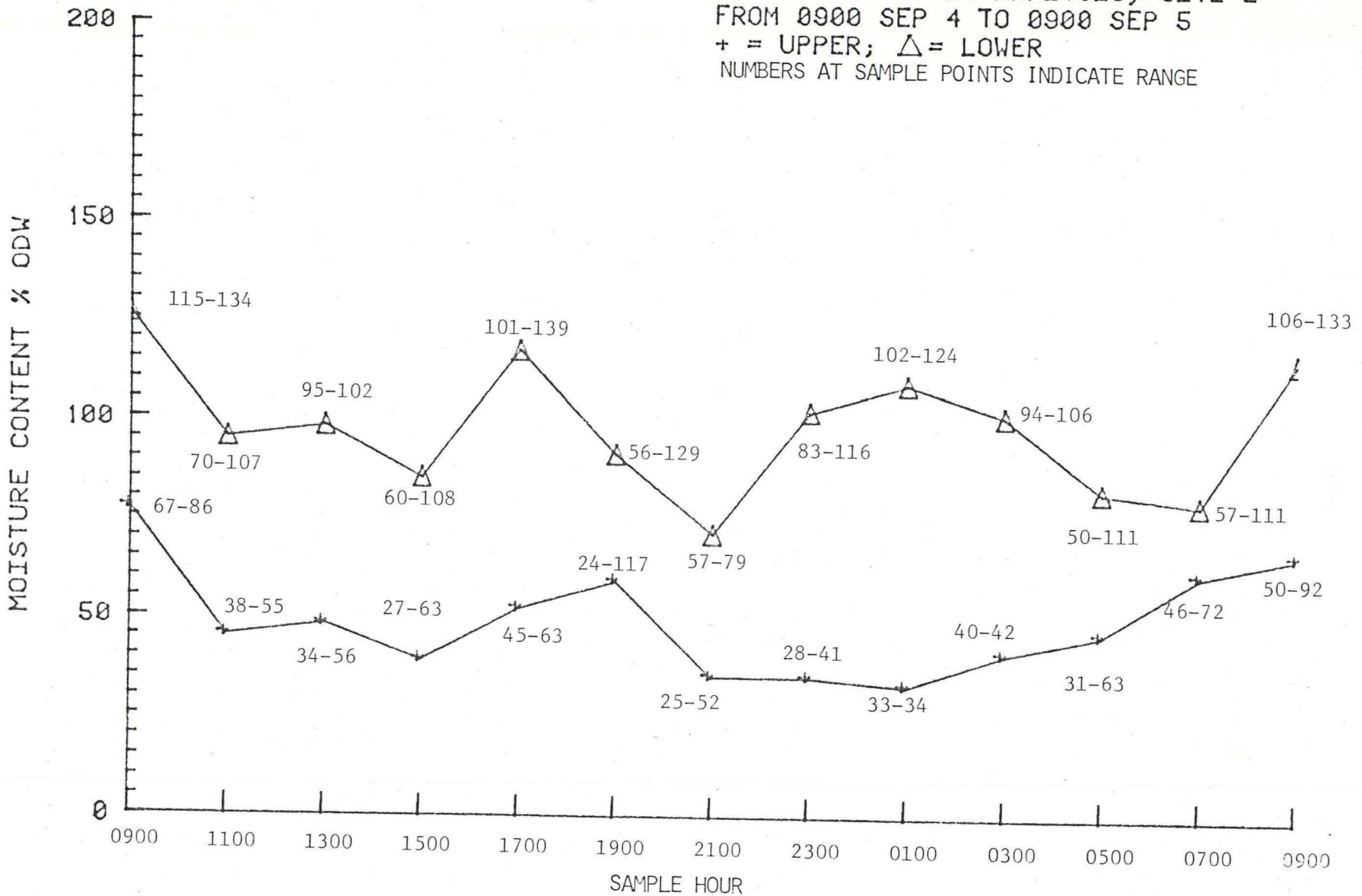


Figure 7: 24 HOUR MOISTURE ANALYSIS, SITE 3
FROM 0930 AUG 28 TO 0930 AUG 29
+ = UPPER; △ = LOWER
NUMBERS AT SAMPLE POINTS INDICATE RANGE

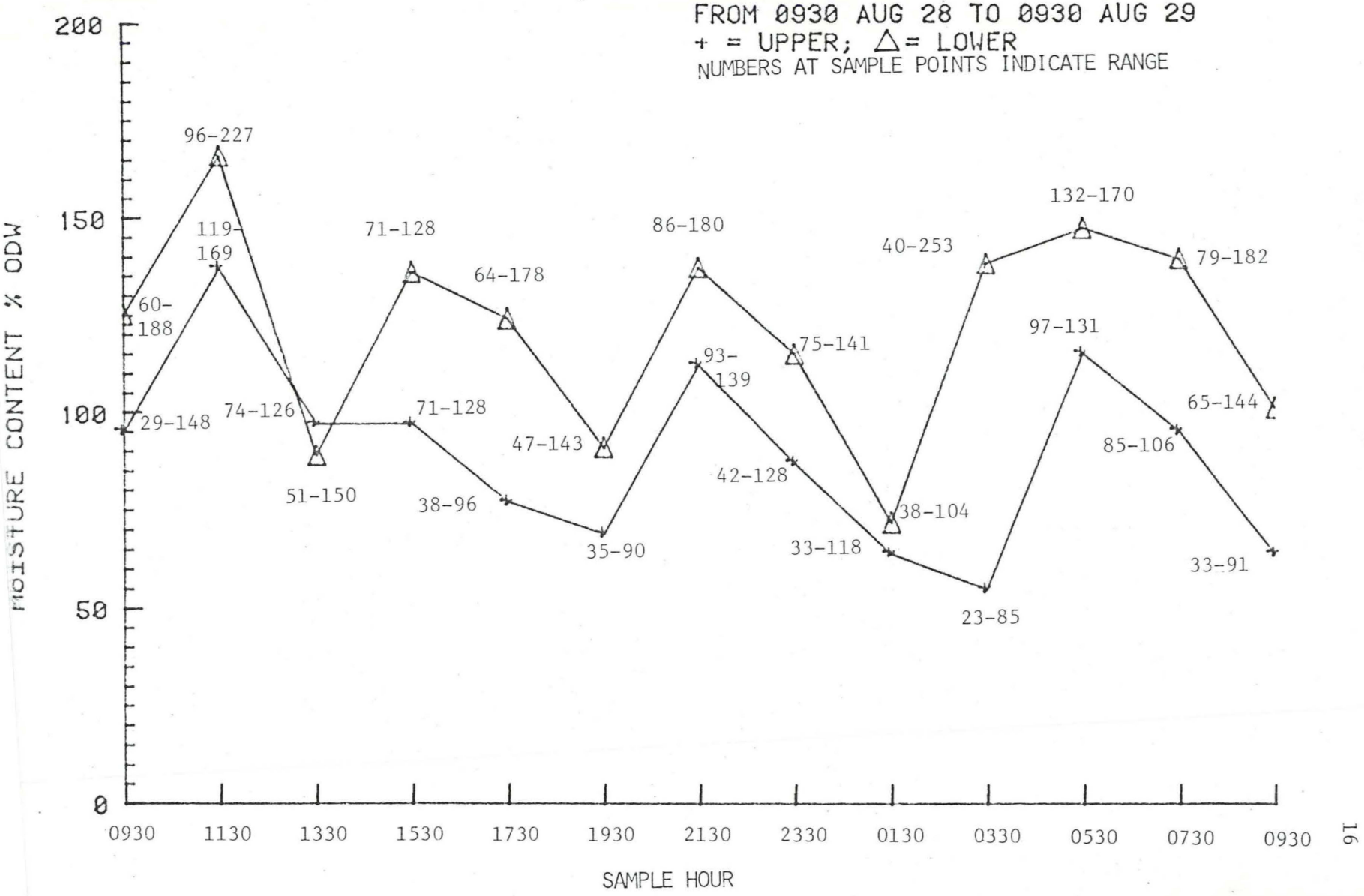
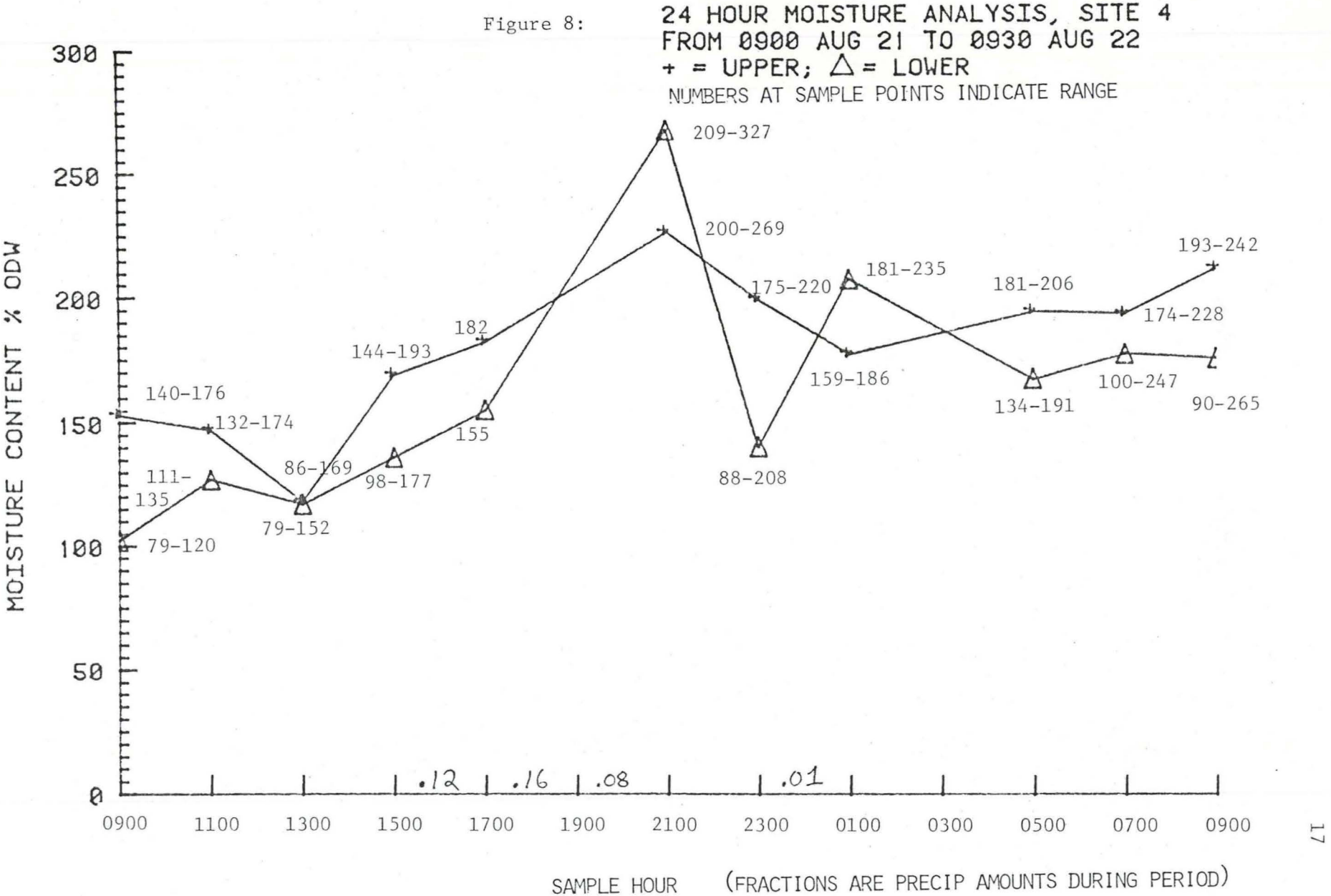


Figure 8:


24 HOUR MOISTURE ANALYSIS, SITE 4
FROM 0900 AUG 21 TO 0930 AUG 22
+ = UPPER; △ = LOWER
NUMBERS AT SAMPLE POINTS INDICATE RANGE
MOISTURE CONTENT % ODW
300
250
200
150
100
50
0
140-176
132-174
111-135
79-120
86-169
79-152
144-193
98-177
182
155
209-327
88-208
200-269
175-220
159-186
181-235
181-206
134-191
174-228
100-247
193-242
90-265
.12
.16
.08
.01
0900
1100
1300
1500
1700
1900
2100
2300
0100
0300
0500
0700
0900
SAMPLE HOUR
(FRACTIONS ARE PRECIP AMOUNTS DURING PERIOD)

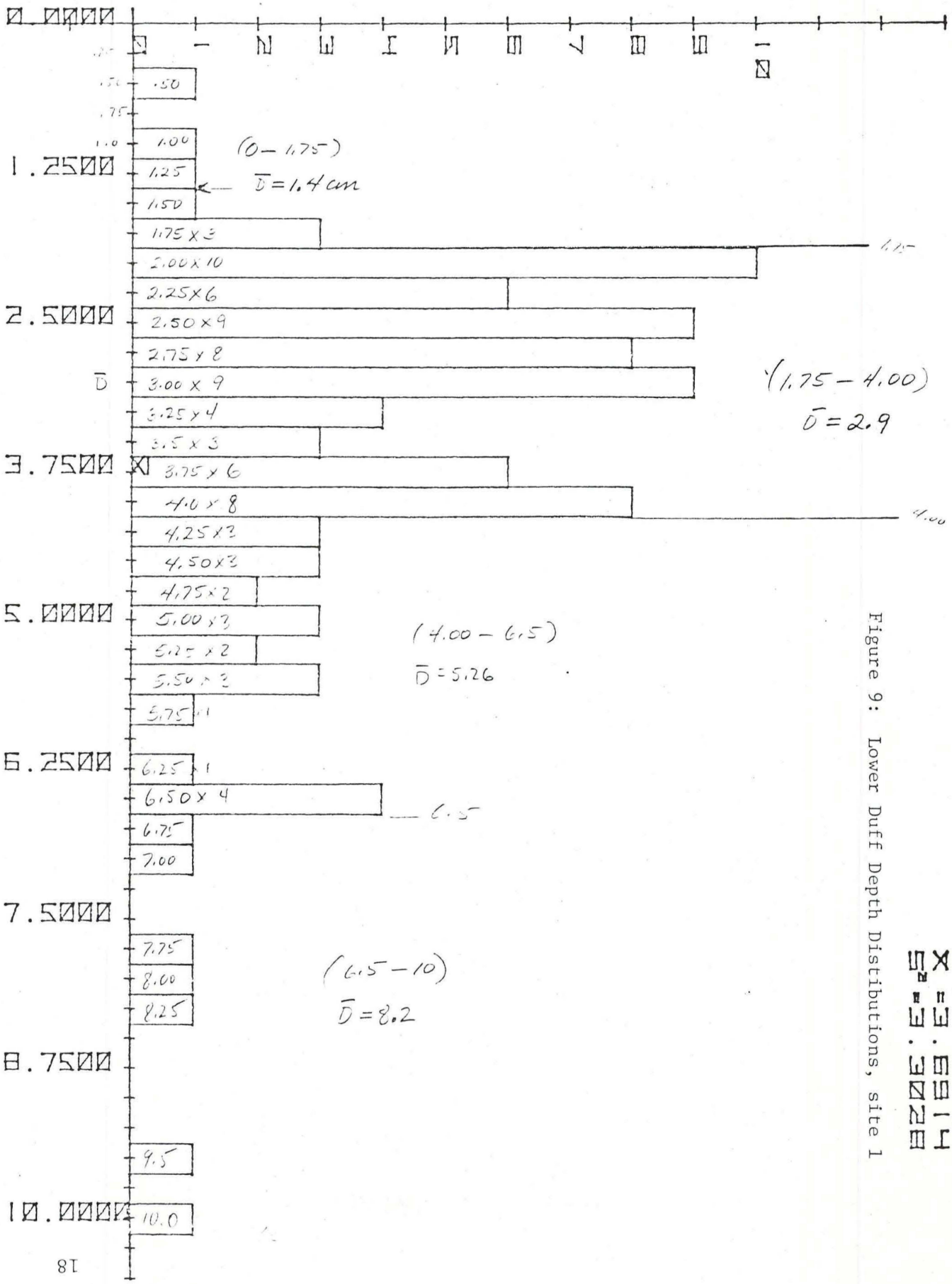


Figure 9: Lower Duff Depth Distributions, site 1

$\bar{X} = 3.6514$
$S^2 = 3.3028$

Figure 10: Lower Duff Depth Distributions, site 2

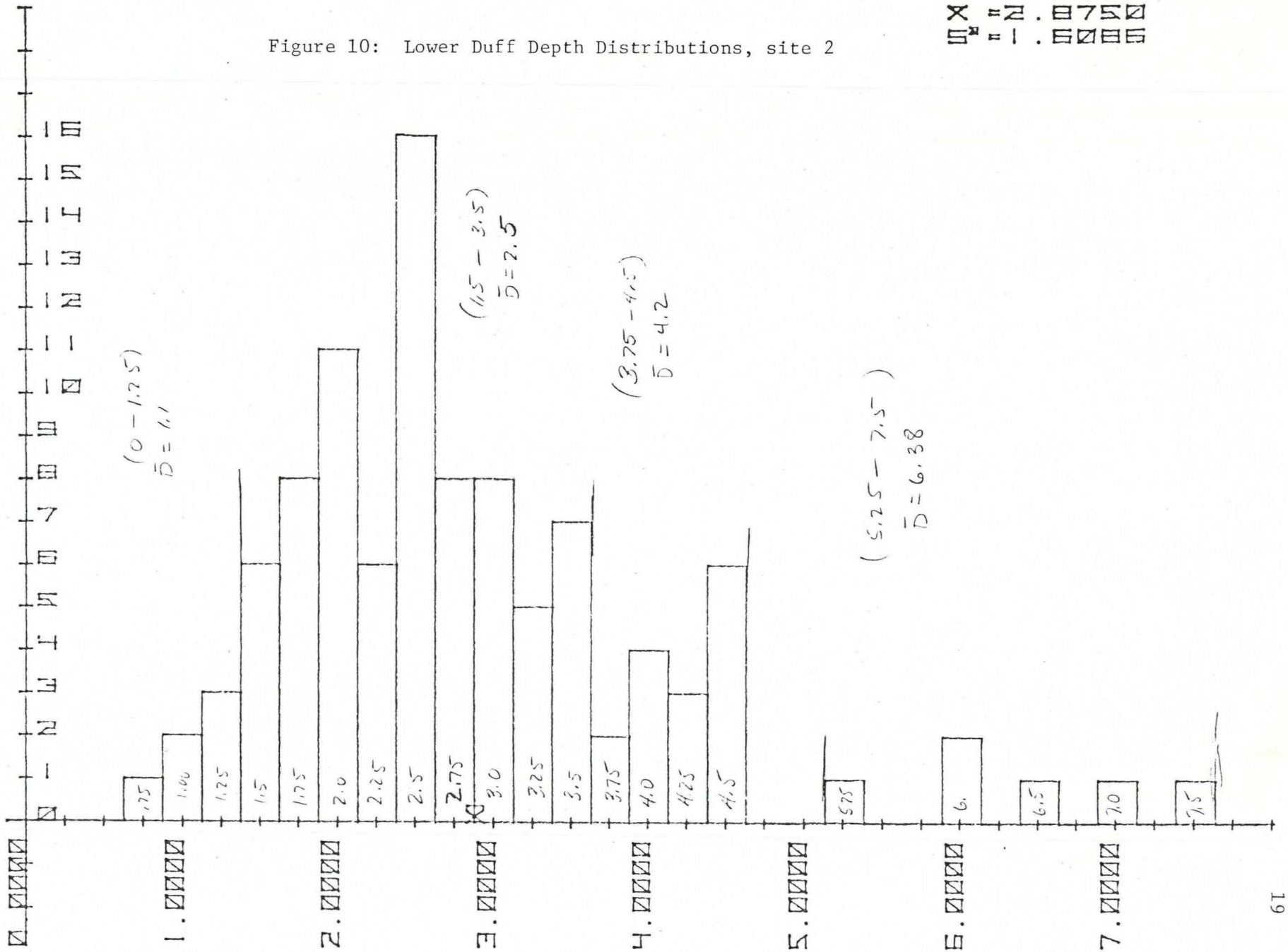


Figure 11: Lower Duff Depth Distributions, site 3

Figure 12: Lower Duff Depth Distributions, site 4

MODEL VALIDATION

For calibrating DUFF, Fosberg (communication) suggested initial values of about .7 for both ζ_T and ζ_M.

These factors are inversely proportional to the exchange rate of heat and water vapor (T & ρ) as defined on page 4. Best fitting values used for the sites in this experiment were .76 for ζ_T and .42 for ζ_M of the upper layer, and .35 for the lower layer (ζ_M only).

Bulk densities, particle densities, hydraulic conductivities, and particle time lags were taken from Fosberg (1975) and Fosberg (1977). A layer of sand 200 cm. thick was used as the bottom layer for simulating a heat and moisture sink. Table 3 lists input values that were the same in all simulation runs. Table 4 shows the ranges of the depth groups and resulting ranges of layer moisture and temperature time lags.

Using the listed input values and weather data for each site, simulations were run for each depth group at each site. Weather information was entered at 2-hour intervals every day from 1 August until 18 October. The timestep in the simulation was 7600 seconds.

Observed moisture contents and predicted values are plotted in Figures 13-16 for Sites 1-4 respectively. For 24-hour analysis, observed and predicted values are plotted in Figures 17-20 for Sites 1-4 respectively.

Table 3: Constant Input Parameters in Simulation Runs

Layer	Layer Thickness (cm)	Bulk Dens. gm/cm^3	Part. Dens. gm/cm^3	ζ_T	ζ_M	Hydraulic Cond. cm/s	Part. Moist Timelag min	Part. Temp. Timelag min
upper	.30	.08	.47	.76	.42	.1333	75	.009
lower	variable	.20	.47	.76	.35	.02	1.6	.009
bottom	200.	1.46	2.6	1.	1.	.04	.0007	.0001

Table 4: Layer Thicknesses and Computed Layer Timelags

	Thickness (cm)	Layer Moisture Timelag (minutes)	Layer Temperature Timelag (minutes)
All Sites			
Upper	.30	36	1.9
Bottom	200.0	1532	1515
Site 1	1.4 - 8.2	257 - 2684	48 - 505
Site 2	1.1 - 6.4	354 - 3735	67 - 704
Site 3	2.4 - 8.5	726 - 3918	137 - 738
Site 4	1.1 - 15.6	257 - 8805	48 - 1659

Figure 13:

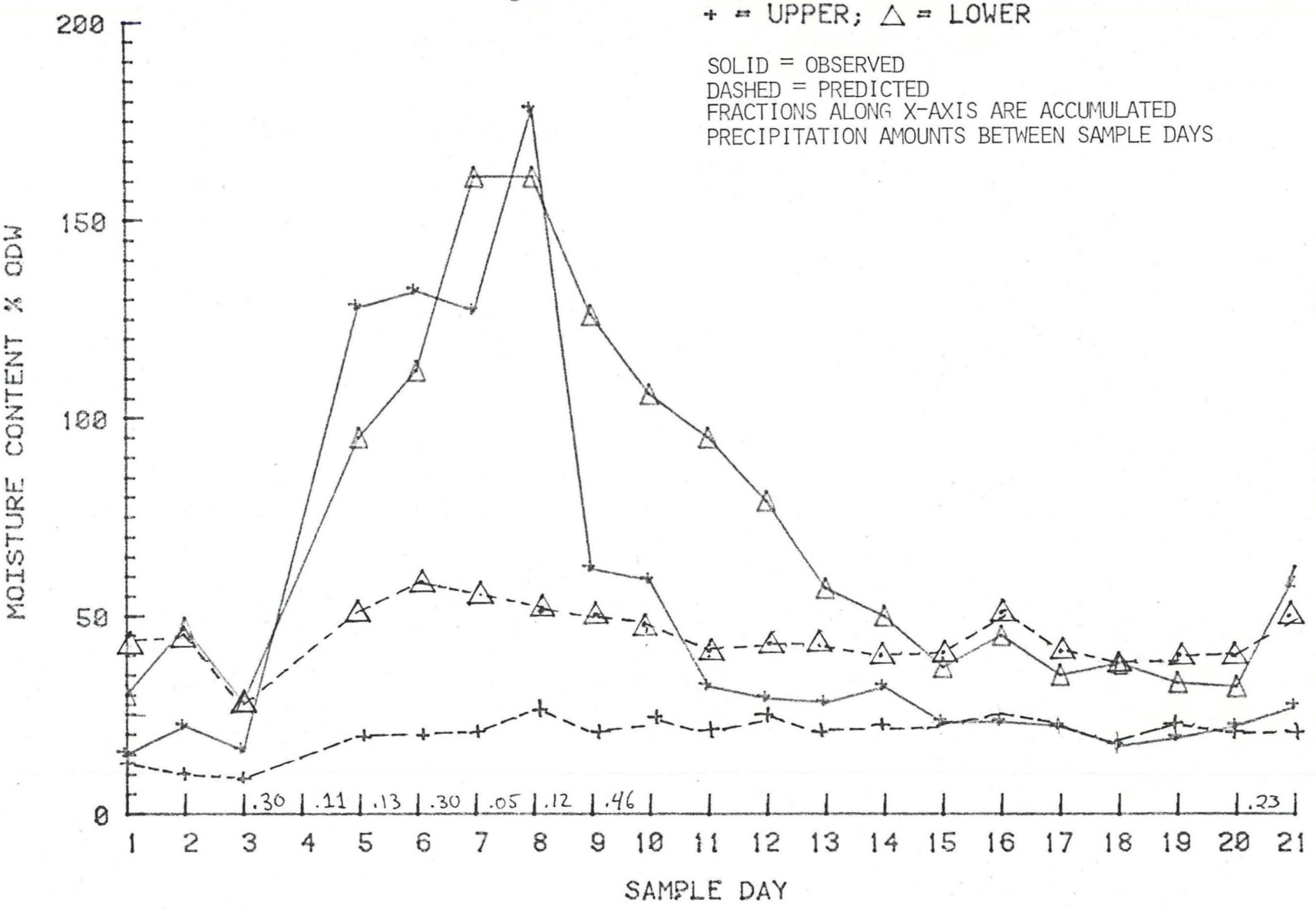

MEAN DUFF MOISTURE, SITE 1
+ = UPPER; △ = LOWER
SOLID = OBSERVED
DASHED = PREDICTED
FRACTIONS ALONG X-AXIS ARE ACCUMULATED
PRECIPITATION AMOUNTS BETWEEN SAMPLE DAYS
MOISTURE CONTENT % ODW
200
150
100
50
0
.30
.11
.13
.30
.05
.12
.46
.23
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
SAMPLE DAY

Figure 14:

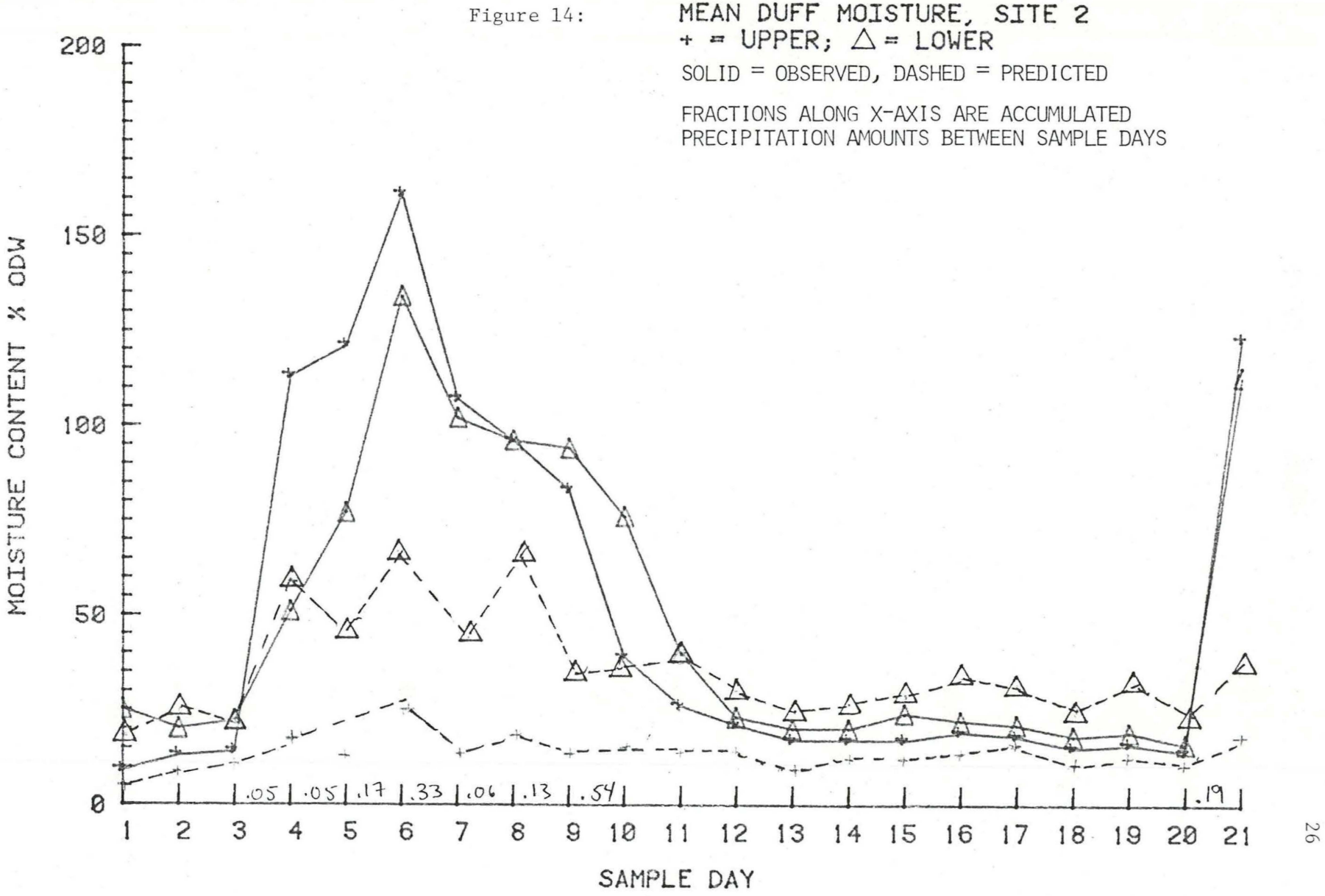

MEAN DUFF MOISTURE, SITE 2
+ = UPPER; △ = LOWER
SOLID = OBSERVED, DASHED = PREDICTED
FRACTIONS ALONG X-AXIS ARE ACCUMULATED
PRECIPITATION AMOUNTS BETWEEN SAMPLE DAYS
MOISTURE CONTENT % ODW
200
150
100
50
0
.05
.05
.17
.33
.06
.13
.54
.19
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
SAMPLE DAY

Figure 15:

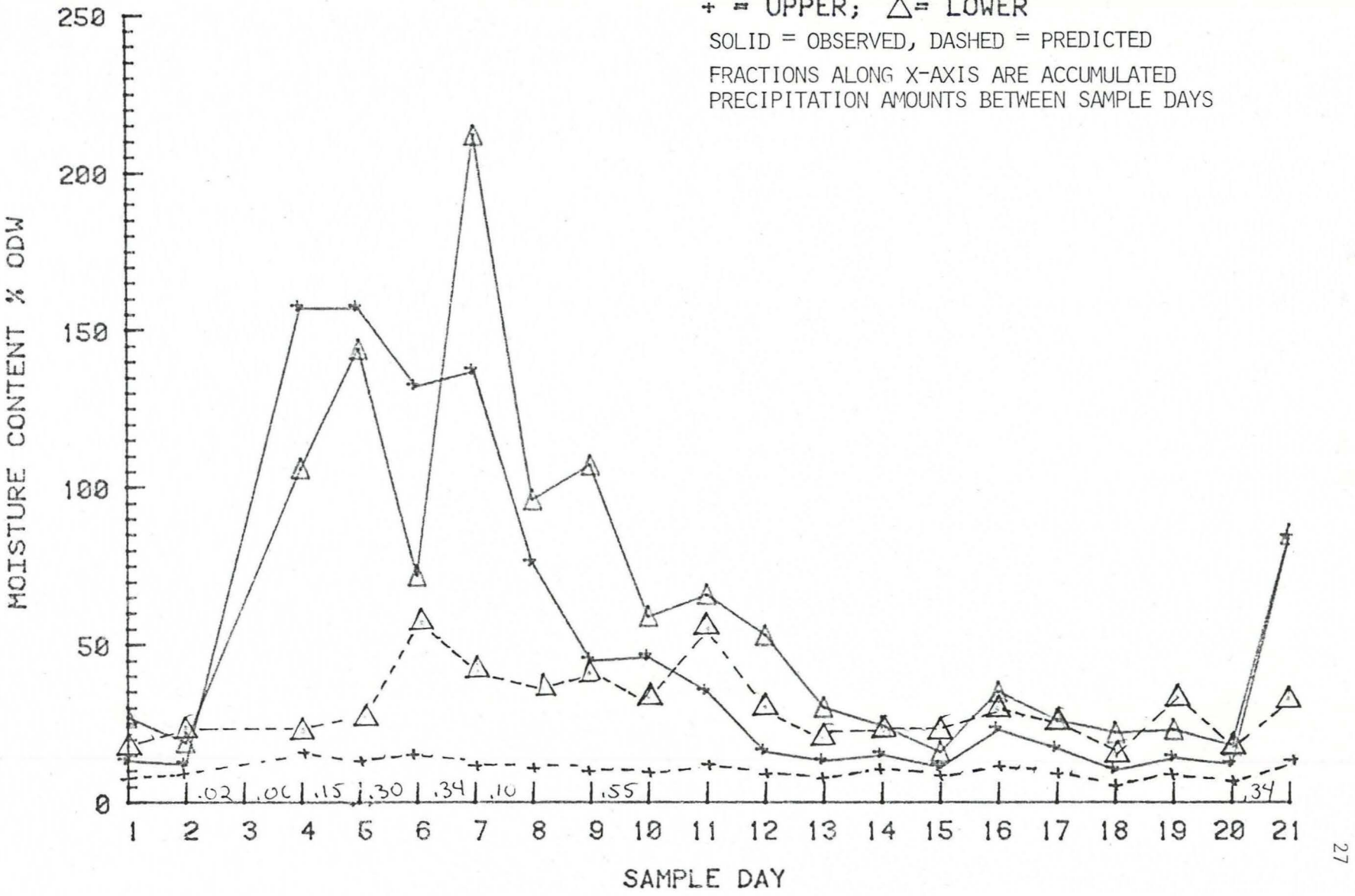

MEAN DUFF MOISTURE, SITE 3
+ = UPPER; △= LOWER
SOLID = OBSERVED, DASHED = PREDICTED
FRACTIONS ALONG X-AXIS ARE ACCUMULATED
PRECIPITATION AMOUNTS BETWEEN SAMPLE DAYS
MOISTURE CONTENT % ODW
250
200
150
100
50
0
.02
.00
.15
.30
.34
.10
.55
.34
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
SAMPLE DAY

Figure 16:

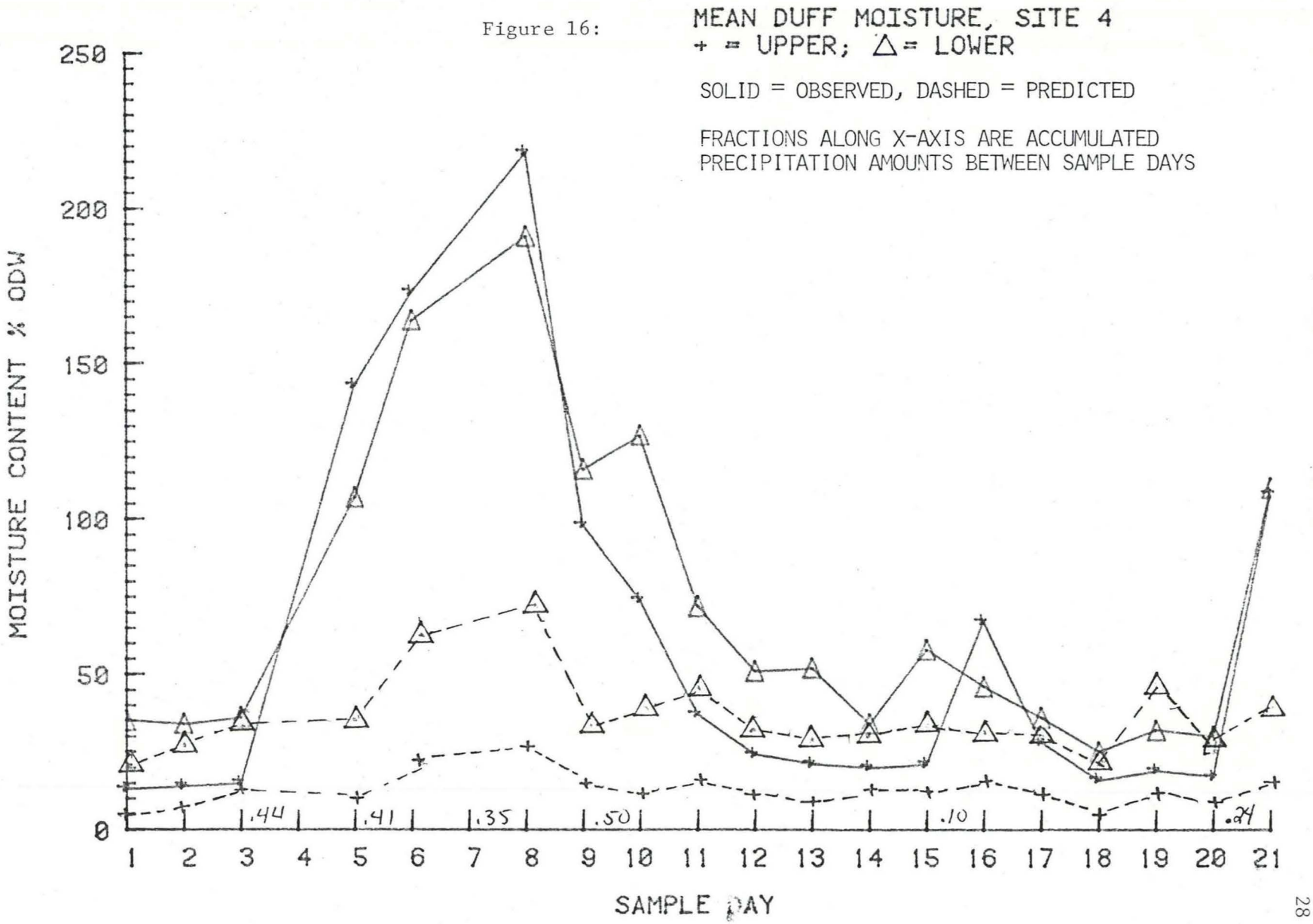

MEAN DUFF MOISTURE, SITE 4
+ = UPPER; △ = LOWER
SOLID = OBSERVED, DASHED = PREDICTED
FRACTIONS ALONG X-AXIS ARE ACCUMULATED
PRECIPITATION AMOUNTS BETWEEN SAMPLE DAYS
MOISTURE CONTENT % ODW
250
200
150
100
50
0
.44
.41
.35
.50
.10
.24
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
SAMPLE DAY

Figure 17: 24 HOUR MOISTURE ANALYSIS, SITE 1
FROM 0930 SEP 11 TO 0930 SEP 12
□ = UPPER; △ = LOWER
SOLID = OBSERVED; DASHED = PREDICTED

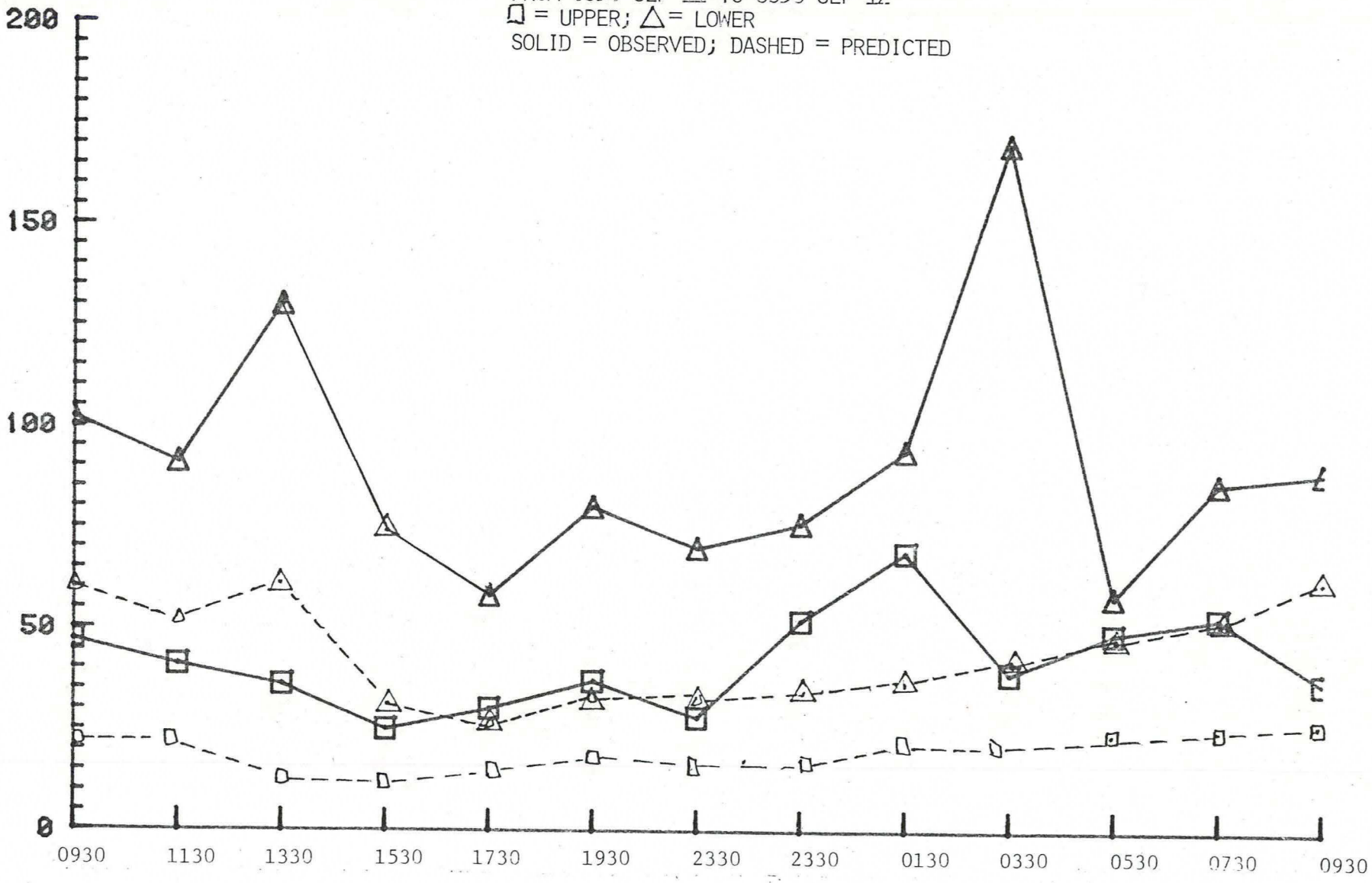


Figure 18:

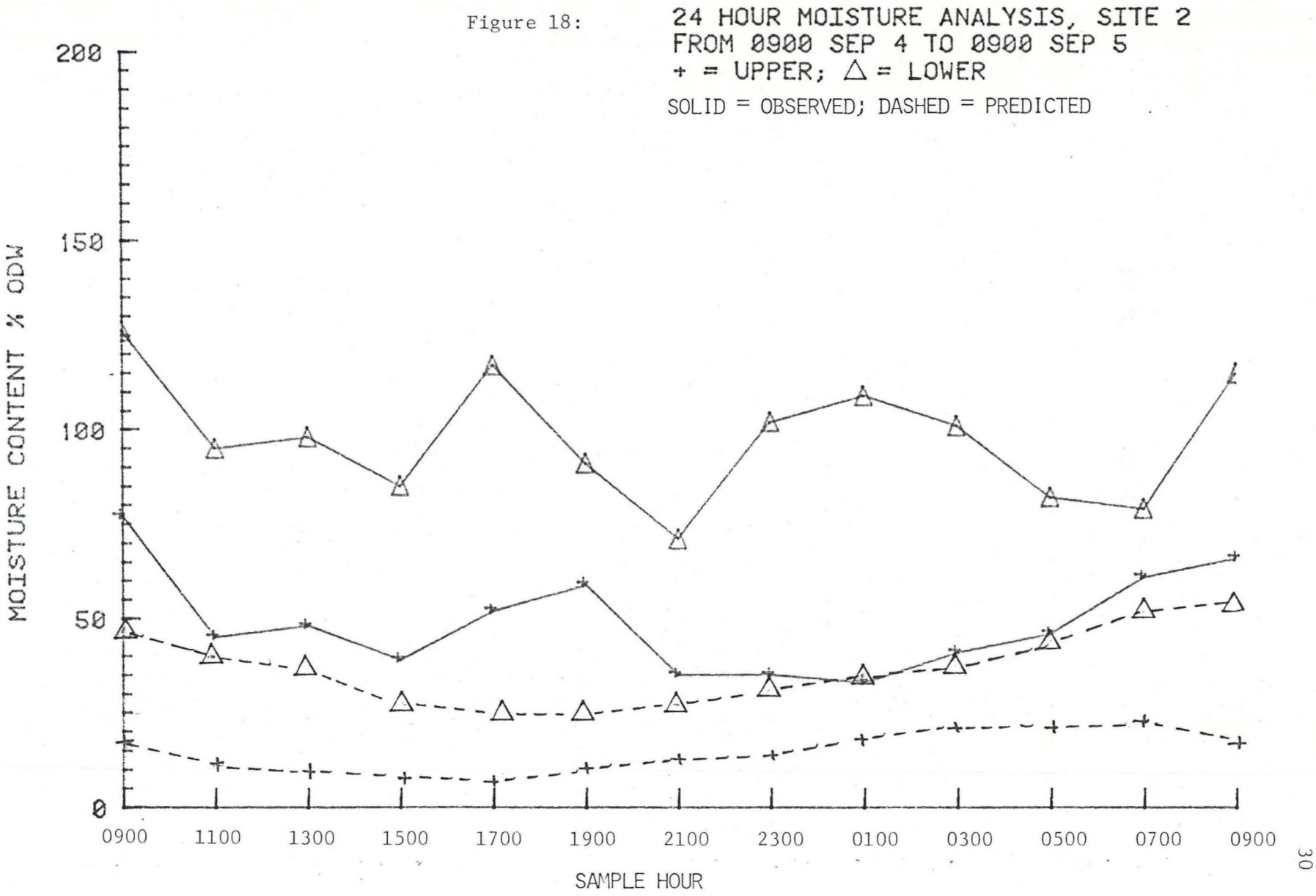

24 HOUR MOISTURE ANALYSIS, SITE 2
FROM 0900 SEP 4 TO 0900 SEP 5
+ = UPPER; △ = LOWER
SOLID = OBSERVED; DASHED = PREDICTED
MOISTURE CONTENT % ODW
200
150
100
50
0
0900
1100
1300
1500
1700
1900
2100
2300
0100
0300
0500
0700
0900
SAMPLE HOUR

Figure 19:

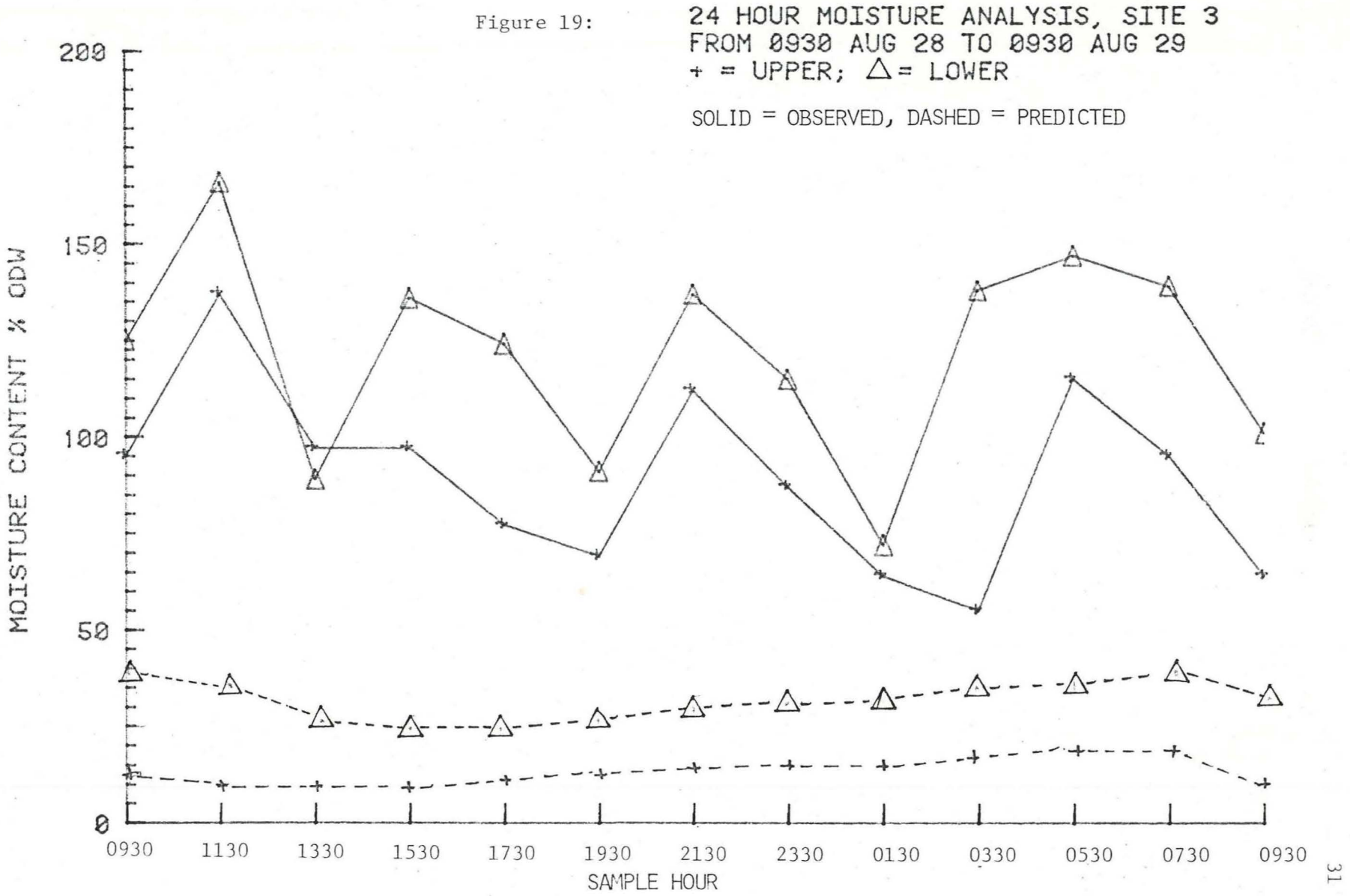
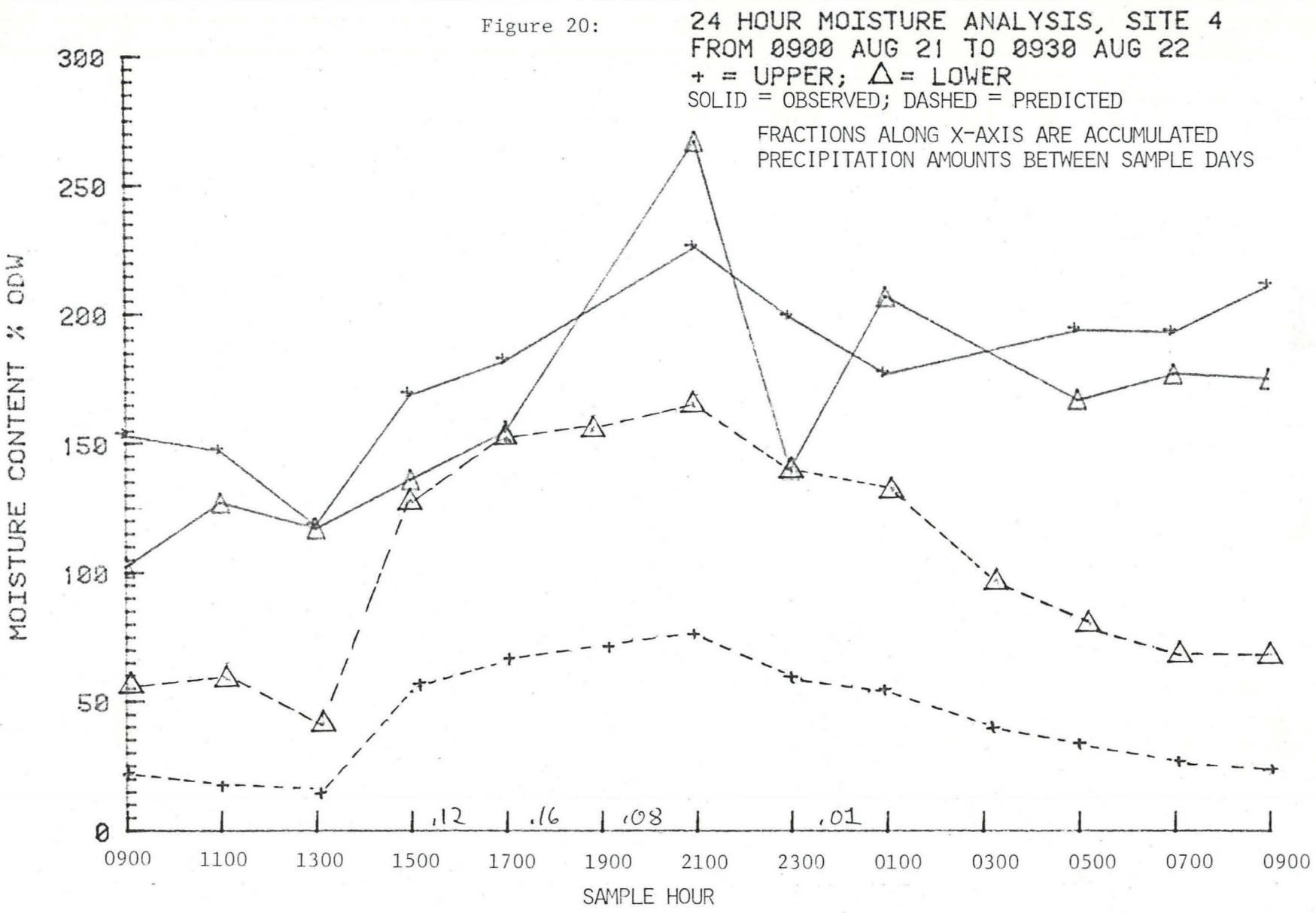

24 HOUR MOISTURE ANALYSIS, SITE 3
FROM 0930 AUG 28 TO 0930 AUG 29
+ = UPPER; △ = LOWER
SOLID = OBSERVED, DASHED = PREDICTED
MOISTURE CONTENT % ODW
200
150
100
50
0
0930
1130
1330
1530
1730
1930
2130
2330
0130
0330
0530
0730
0930
SAMPLE HOUR

Figure 20:


24 HOUR MOISTURE ANALYSIS, SITE 4
FROM 0900 AUG 21 TO 0930 AUG 22
+ = UPPER; Δ = LOWER
SOLID = OBSERVED; DASHED = PREDICTED
FRACTIONS ALONG X-AXIS ARE ACCUMULATED
PRECIPITATION AMOUNTS BETWEEN SAMPLE DAYS
MOISTURE CONTENT % ODW
300
250
200
150
100
50
0
.12
.16
.08
.01
0900
1100
1300
1500
1700
1900
2100
2300
0100
0300
0500
0700
0900
SAMPLE HOUR

DISCUSSION

Daily observed and predicted curves follow each other in shape throughout the season of sampling. Predicted values are mostly below observed values during the wet, rainy period (sample days 3 through 12). The model predicts moisture loss after percipitation end at a rate faster than that observed. This may indicate the need to consider the problem of puddling caused by the bottom layer. Lowering a layers hydraulic conductivity increased the volumetric moisture content of the layer during periods of rain; but to get moisture content values on the order of 175 percent and above, conductivities of magnitude 10^{-3} were needed. This is several orders of magnitude lower than those reported by Fosberg (1977).

On the twenty-four hour analysis at site 4, rain occurred at four intervals during the course of the sample. The model did very well during this period from 1500 - 2300, 21 August. Predicted values of moisture content top out at about 150 percent and then decline. Again, the rate of loss predicted is greater than that observed but the actual prediction of moisture content during the rain periods is very encouraging.

The predicted values of duff moisture were surprisingly insensitive to the four groups of lower depths which were simulated at each site. Despite the range of resulting timelags (Table 4), moisture contents from the four groups were usually within three to seven percent of each other. The maximum range was fifteen percent.

The model performed best for predicting moisture contents in the range of 10 to 35 percent with no influence of rain for several days prior. In

In twenty-four hour analysis, predictions were generally far below observed values except at site 4 during the rain. The model picks up the general pattern of diurnal changes, but does not deal with some of the wild hour-to-hour flucuations observed during the twenty-four hour periods.

The results of the model predictions indicate that an analysis of the predicted-to-observed ratios may be an empirical tool for adjusting moisture contents to values closer to those observed. The adjustments should consider the predicted value and length of time since the last period of rain. This adjustment could become a set function in the model or a user defined value. The user defined value has advantages as the model becomes calibrated to more geographical areas. This work is currently being conducted by Bill Frandsen and should be reported in the near future.

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APPENDIX A

USE INSTRUCTIONS FOR PROGRAM

DUFF

SYSTEMS FOR ENVIRONMENTAL MANAGEMENT

P. O. BOX 3776
MISSOULA, MONTANA 59806
PHONE: (406) 549-7478

7 June 1979

Instructions for use of program

DUFF

Purpose : Program DUFF is a computer adaptation of Michael Fosberg's[1] theoretical model of moisture and heat transport in coniferous forest duff/humus horizons.

Language : ASCII standard FORTRAN IV, four bit word output.

Location : DUFF is stored on magnetic tape number 09177 at the Lawerence Berkeley Laboratory (LBL) tape library. The Berkeley computer center (BKY) maitains CDC machines and software. The BKY UPDATE version of DUFF is the 5th file on the tape, the compiled object code is the 6th file on tape 09177.

Program Logic

Step 1: Set program constants.
Step 2: Read program control information.
Step 3: Read horizon structure data.
Step 4: If first time of simulation, calculate physical characteristics of each layer of the duff/humus bed.
Step 5: Output to printer bed characteristics.
Step 6: If beginning of season, call routine PROFL1 to set initial temperature and moisture profiles of bed.
Step 7: Begin simulation loops.

a. Read weather observation
b. If rain in last period, call routine PERCOL. PERCOL determines free water in horzons due to rain infiltration and the equilibrium moisture content of particles due to adsorption of free water.
c. If no rain in last period, calculate moisture content by standard time-lag methods unless moisture content is above saturation. Then use adsorption/desorption methods of PERCOL (2-15% moisture content change per hour, stress dependent).
d. Do next timestep simulation.

Step 8: Print model output to printer in intervals specified in Step 2 input.

DATA DEPENDENCIES (in order of input)

A. Program Control

Parameter	Units	Variable
1. Number of horizons in bed	--	NLYR
2. Simulation time step	sec	DELTM
3. Number of simulation interations printed to line printer	--	PRTSTP
4. Number of simulation interations between outputs to line printer	--	SKPSTP
5. Number of plots to simulate	--	NPLOT

Format

210 FORMAT(I2,F10.0,3I3)

Logical Input Device

Cards (TAPE5)

B. Plot Documentation

Parameter	Variable
1. 80 columns of personal documentation on plot or other information. Is printed at the top of each page of output.	HEAD

Format

220 FORMAT(20A4)

Logical Input Device

Cards (TAPE5)

C. Bed Horizon Characteristic (one card for each layer of NLYR)

Parameter	Units	Variable
1. Duff/Humus type code (see table 1)	--	ITYPE
2. Layer thickness	cm	HZTHK

	Parameter	Units	Variable
3.	Particle temperature time-lag	sec	TATMPP
4.	Particle moisture time-lag	sec	TAUROP
5.	Layer bulk density	gm/cm^3	RHOBLK
6.	Layer particle density	gm/cm^3	ROPART
7.	Layer hydraulic conductivity	cm/sec	HYDROK
8.	Moisture response time-lag coeff	--	ZETARO
9.	Temperature response time-lag coeff	--	ZETTMP

Notes: See table 2 for suggested values

Format

```
230  FORMAT(I2,F8.2,7F10.4)
```

Logical Input Device

Cards (TAPE5)

D. Meteorological Inputs

	Parameter	Units	Variable
1.	Month	1-12	MONTH
2.	Day	1-31	IDAY
3.	Hour	1-24	IHOUR
4.	Temperature	F	TEMP
5.	Relative humidity	%	HUMID
6.	Precipitation amount since last observation	in x 100	IPREC

Format

```
550 FORMAT(3I2,3X,2F3.0,I4)
```

Logical Input Device

Disk ** (TAPE15) **

DATA DECK STRUCTURE

Data Deck
- Program control card — (first card in data deck)
- Plot documentation card
- Bed horizon characteristic card
- " " " "
- " " " "
- (until NLYR cards)

(this block is repeated for each plot (NPLOT))

- EOR — (last card in data deck)

SAMPLE RUNSTREAM (without program modifications)

```
JØB CARD (default time and storage)
FETCHMT,LGØ,09177,D9,QT,5FS,1F.
FETCHMT,TAPE15, (appropriate sequence to get weather data)
LGØ.
EØR (7/8/9)
                    }
                    } DATA DECK
                    }
EØF (6/7/8/9)
```

SAMPLE RUNSTREAM (with program modifications)

```
JØB CARD (default time and storage)
FETCHMT,ØLDPL,09177,D9,QT,4FS,1F.
UPDATE,F,D.
DELETE,ØLDPL.
MNF4,I=CØMPILE,L=0.
DELETE,CØMPILE.
FETCHMT,TAPE15,  (get weather data)
LGØ.
EØR
*IDENT NAME     (NAME is change name or number)
                    }
                    } BKY UPDATE change deck (see HANDBOOKS)
                    }
EØR
                    }
                    } DATA DECK
                    }
EØF
```

Table 1: Duff/Humus type codes

Duff/Humus Type	Code
LPP Duff	1
LPP Humus	2
PP Duff	3
PP Humus	4
DF Duff	5
DF Humus	6
Sand (assumed organic bottom layer)	7

Table 2: Typical values of particle/layer characteristics

	TATMPP	TAUROP	RHOBLK	ROPART	HYDROK	ZETTARO	ZETTMP
LPP Duff	.100	4000.	.093	.600	.05 - 30	.3 - .5	.6 - .8
LPP Humus	.100	4000.	.271	.560	"	"	"
PP Duff	.110	5000.	.081	.510	"	"	"
PP Humus	.110	5000.	.264	.470	"	"	"
DF Duff	.100	4500.	.093	.510	"	"	"
DF Humus	.100	4500.	.124	.600	"	"	"
Sand	.0016	.0400	1.46	2.60	.0417	.8 - 1.	.8 - 1.

1. Fosberg, Michael A. Heat and water transport properties in conifer duff and humus. 1975.

APPENDIX B

PROGRAM DUFF DOCUMENTATION

DOCUMENTATION

COMMON BLOCKS USED

COMMON /BLOCK1/ : contains parameters used in duff moisture calculations, statified by layer (1-10).

ARRAYS	:	DESCRIPTION
TEMP	:	temperature of horizon (degrees K)
HUMID	:	relative humidity of horizon voids (%)
DEPTH	:	depth of layer from surface (cm)
ESAT	:	saturation vapor pressure of layer voids (dynes/cm^3)
EPRES	:	vapor pressur of layer voids (dynes/cm^3)
RHO	:	vapor density of layer voids (gm/cm^3)
ITYPE	:	duff/litter/soil type

VARIABLES	:	DESCRIPTION
TEMPIN	:	surface boundary temperature (degrees K)
HUMIN	:	surface boundary relative humidity (%)
RV	:	gas constant (vapor, cgs units)
NLYR	:	number of layers in horizon structure

COMMON /BLOCK2/ : contains parameters used for simulation and calculation of moisture values in the event of rain, stratified by layer (1-10)

ARRAYS	:	DESCRIPTION
HYDROK	:	hydraulic conductivity of layer (cm/sec)
PERC	:	percolation rate of water through layer voids (cm/sec)
PHI	:	porosity of layer
THETA	:	volumetric moisture content of layer voids (ccH_2O/cc void)
DMC	:	duff moisture content of horizon (%)
DTHETA	:	portion of THETA lost to particle adsorption (%)
SWITCH	:	logical swithc that specifies if layer is simulated at above or below fibersaturation values
EMC	:	particle moisture content of layer (%)
DELTAM	:	rate of water loss or gain by adsorption above saturation levels
RHOBLK	:	bulk density of layer (gm/cm^3)
HZTHK	:	thickness of layer (cm)

VARIABLES	:	DESCRIPTION
PPTAMT	:	rain amount in last time period (cm)
DELTM	:	simulation timestep (sec)
PPTR	:	precipitation rate (PPTAMT/DELTM)
RHOW	:	density of water (gm/cm^3)
FIBSAT	:	particle saturation level (28%)

PROGRAM DOCUMENTATION

PROGRAM DUFF

The logic is:

Step 1: Set program constants.

Step 2: Set up physical characteristics of the duff horizon. These factors include (by layer):

1. Packing ratio (BETA)
2. Porosity (PHI)
3. Vapor Diffusivity (NU)
4. Thermal Diffusivity (KAPPA)
5. Layer Moisture Timelag (TAURHO)
6. Layer Temperature Timelag (TAUTMP)
7. Modified Exponential Exchange Functions (temperature (CHITMP))
8. Modified Exponential Exchange Functions (vapor (CHIRHO))
9. Depth of layer (DEPTH)

Step 3: If it is initial season, call PROFL1 to set up initial temperature and relative humidity profiles of the horizons.

Step 4: Begin simulation

Step 5: Get input values of temperature and relative humidity

Step 6: Begin 24-hour duff moisture simulation (2 hour increments)

Step 7: Use harmonic analysis to model temperature and relative humidity cycles for each time increment.

Step 8: If TPTAMT is greater than zero, and simulation time is less than precipitation duration, it is still raining. GO TO step 10.

Step 9: This means that it has either stopped raining or did not rain.

If EMC is less than RIBSAT regular solution will be used and SWITCH is TRUE for the layer. Otherwise, moisture is lost at the above saturation point rate as defined by DTHETA. This is done for each layer, and skips to step 11.

Step 10: Call PERCOL. This sets a perculation rate of free water through the horizons which is adsorped to an extent by a value of DTHETA, and contributes to the overall moisture content of the horizon by a volumetric amount that is determined by solution of a 3rd degree polynomial equation by subroutine ROOT. This value is determined for each layer, and what adsorped by one layer is not available for adsorption by the next.

Step 11: Determine vapor pressure for each layer and set top layer boundary conditions and intermediate layers to last value of layer above.

Step 12: Modify layer temperature and density by exchange functions.

Step 13: Recalculate vapor pressure using new layer temperature (sat v.p.).

Step 14: Compute current saturation density.

Step 15: If EMC greater than FIBSAT, current density = saturation density.

Step 16: Compute vapor pressure and layer relative humidity from equation of state.

Step 17: If Switch of layer is TRUE get particle moisture by calling EQMC which calculates EQMC of particles based on temperature and relative humidity. Return to Step 6 until analysis is finished.

SUBROUTINE ADSORP (I)

Narrative: Subroutine ADSORP is used in duff moisture calculations during periods that experienced rainfall. ADSORP is called by PERCOL, which was called by DUFF. The parameter I is passed into ADSORP and is the current layer in the duff horizon that is being simulated.

COMMON BLOCKS used: /BLOCK 1/, /BLOCK 2/

The logic is:

Step 1: Solve for effective perculation rate PPP, and then set QQQ and RRR from it.

Step 2: Call ROOT--ROOT returns value for THETA after solving a 3rd degree polynomial equation.

Step 3: Compute particle moisture content adsorption rate (% MC/sec)

Step 4: Compute actual moisture content change (amount = rate x time)

Step 5: Adjust THETA (volumetric content of voids) by amount adsorped by particles.

Step 6: Caluculate effective hydraulic conductivity due to water adsorption.

Step 7: Return to PERCOL

SUBROUTINE EQMC (TEMP, HUMID, EMC, I, ITYPE)

Narrative: Subroutine EQMC computes particle mosite contents based on regression equations for the Wood Products Handbook using temperature and relative humidity as independant variables.

SUBROUTINE PERCOL

Narrative: This subroutine is called by DUFF in the case of precipitation to compute the percolation rate of free water through the duff horizons.

COMMON BLOCKS USED: /BLOCK 1/, /BLOCK 2/

The logic is:

Step 1: Compute precipitation rate.

Step 2: Set percolation rate as the minimum value of the precipitation rate of the hydraulic conductivity of the layer.

Step 3: Call ADSORP to compute THETA and DTHETA for the first layer.

Step 4: Adjust EMC and DMC as affected by THETA and DELTAM set SWITCH to .FALSE.

Step 5: Repeat for lower layers.

Step 6: Return to DUFF.

SUBROUTINE PROFL1

Narrative: This subroutine is called by DUFF to initialize litter/duff horizons to initial values. It is called at the beginning of each plot simulation. The bottom organic layer, and the bottom inorganic layer are assumed to be at fiber saturation, and a linear gradient is established to the surface relative humidity value.

COMMON BLOCKS USED: /BLOCK 1/, /BLOCK 2/

The logic is:

Step 1: Set boundary layer initial conditions.

Step 2: Determine bottom layer subscript.

Step 3: Assume bottom organic layer, and bottom (sand) horizon are saturated.

Step 4: Establish linear gradient of temperature and humidity between top and bottom layers.

Step 5: Calculate vapor pressure and vapor density of each horizon.

Step 6: Return to DUFF.

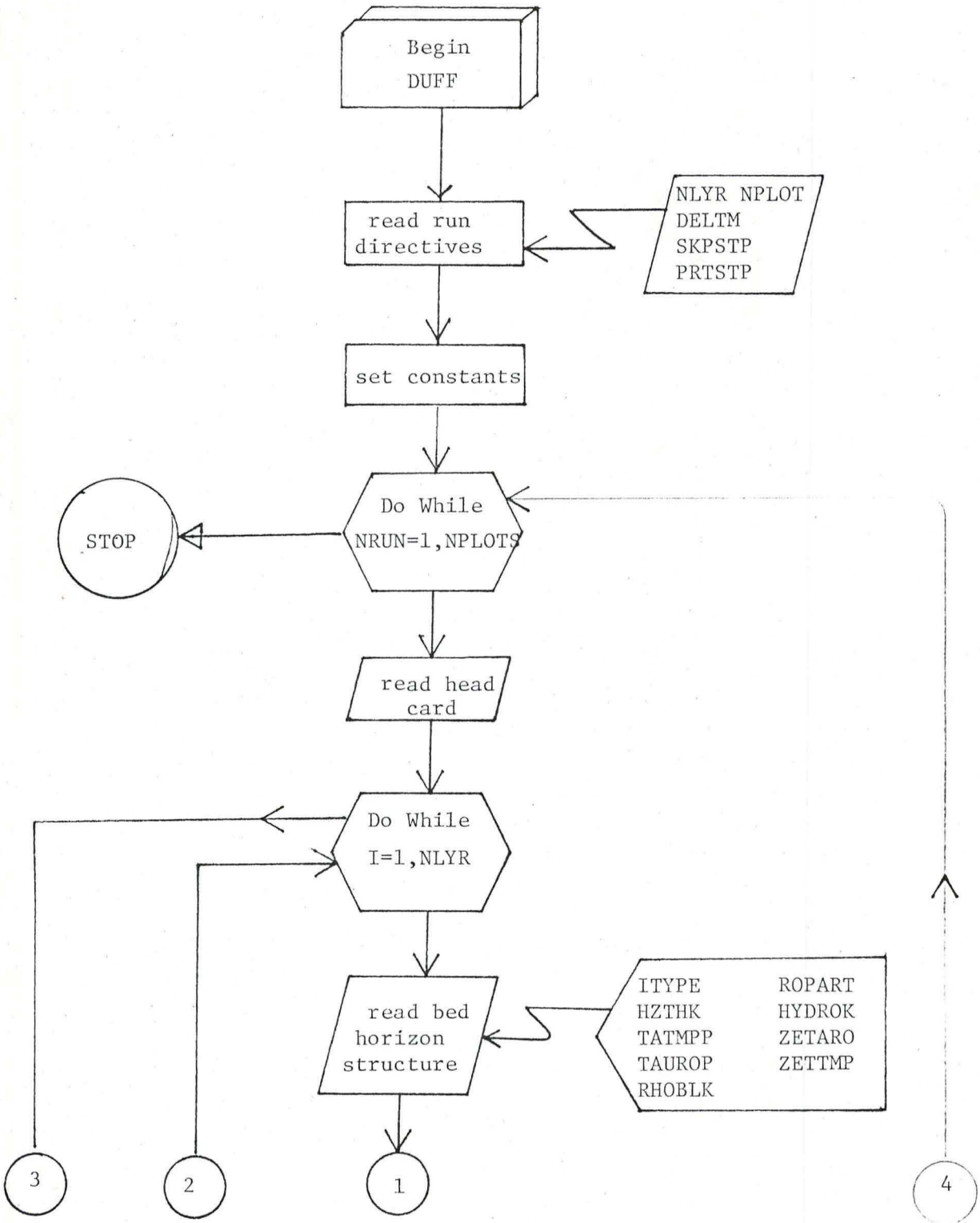
SUBROUTINE ROOT (NC, III, JJJ, PPP, QQQ, RRR, ADFM)

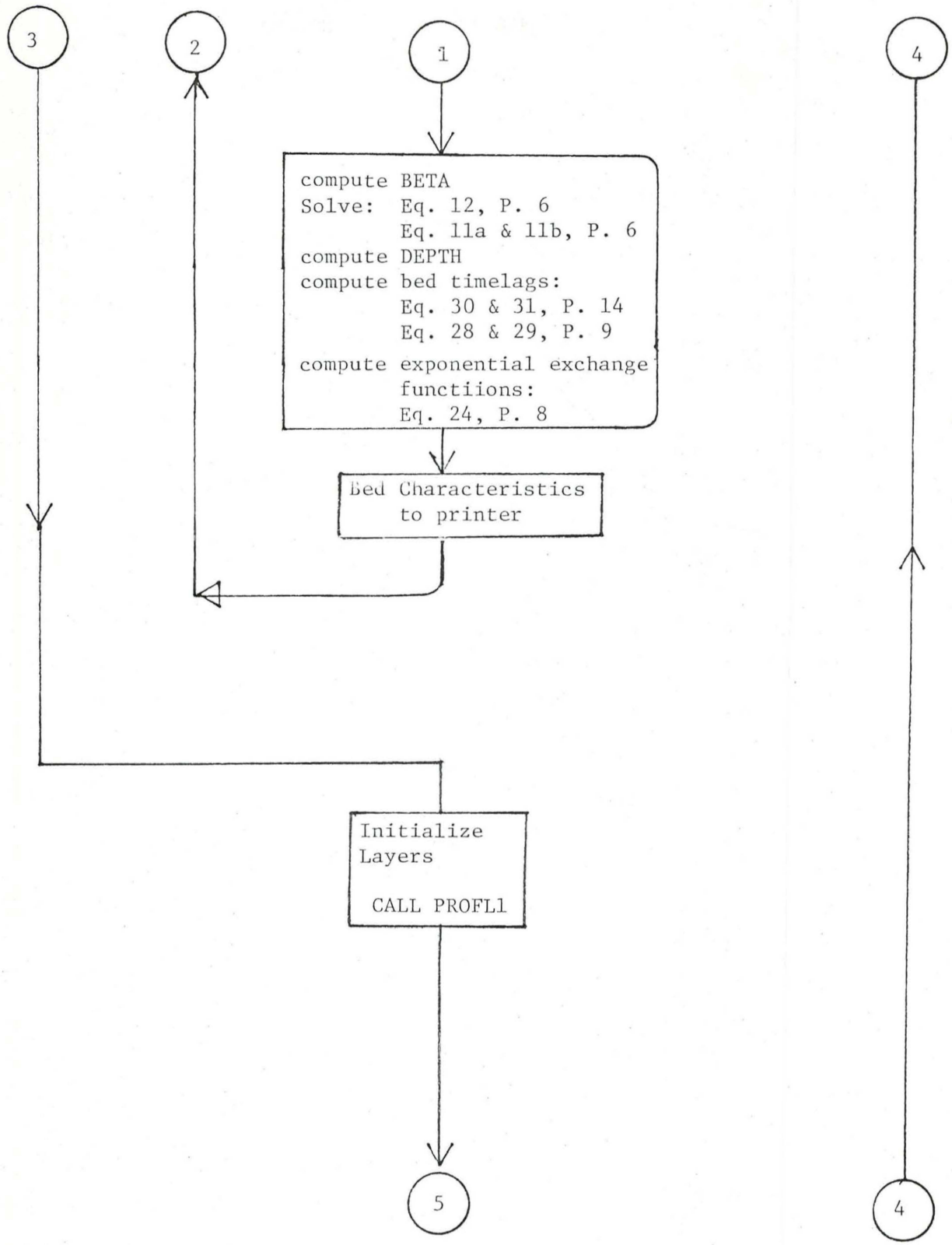
Narrative: This subroutine solves an Nth degree polynomial by numerical methods. I don't know how it works, and will not attempt an explanation. It was given to the project by Mike Fosberg.

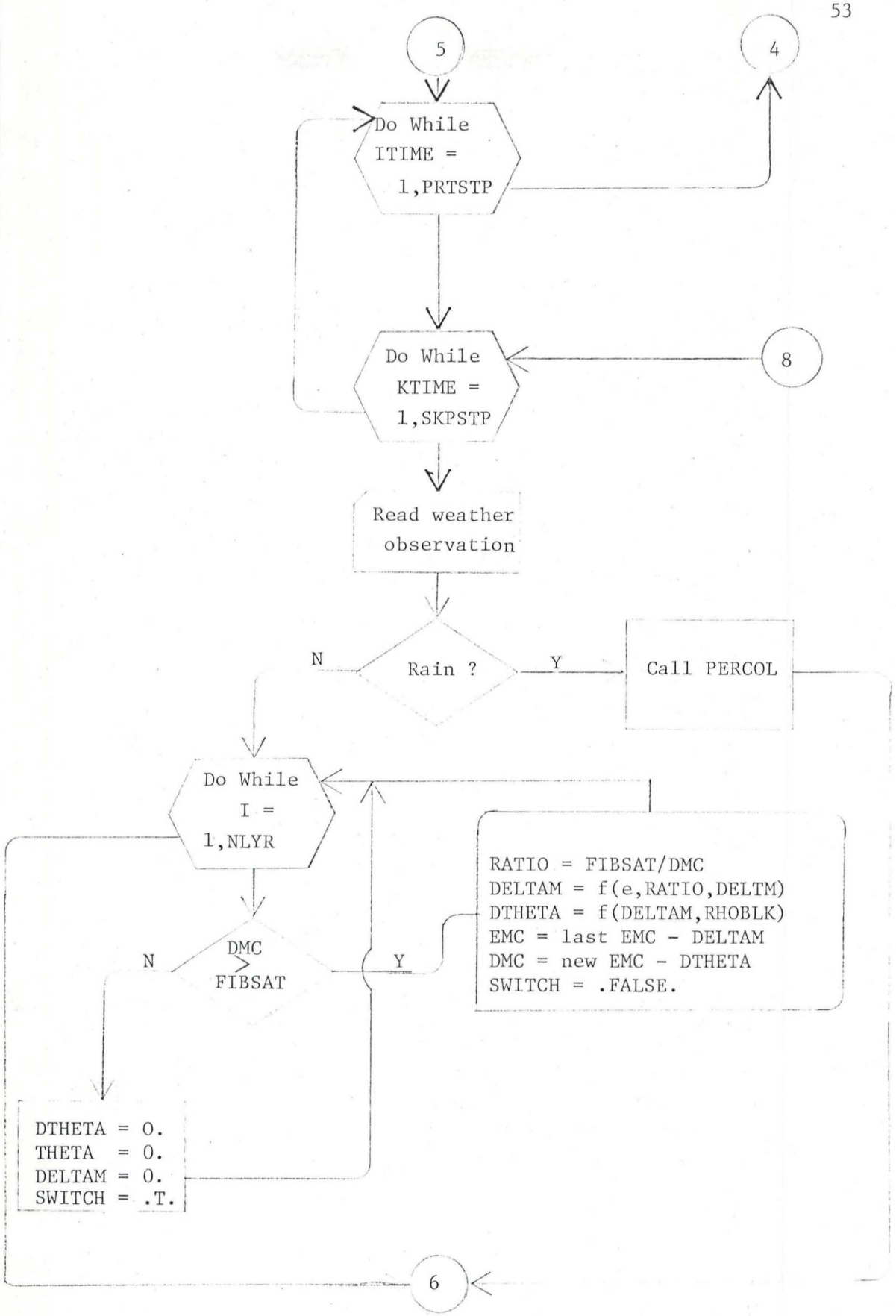
SUBROUTINE VAPOR (TEMP, ESAT)

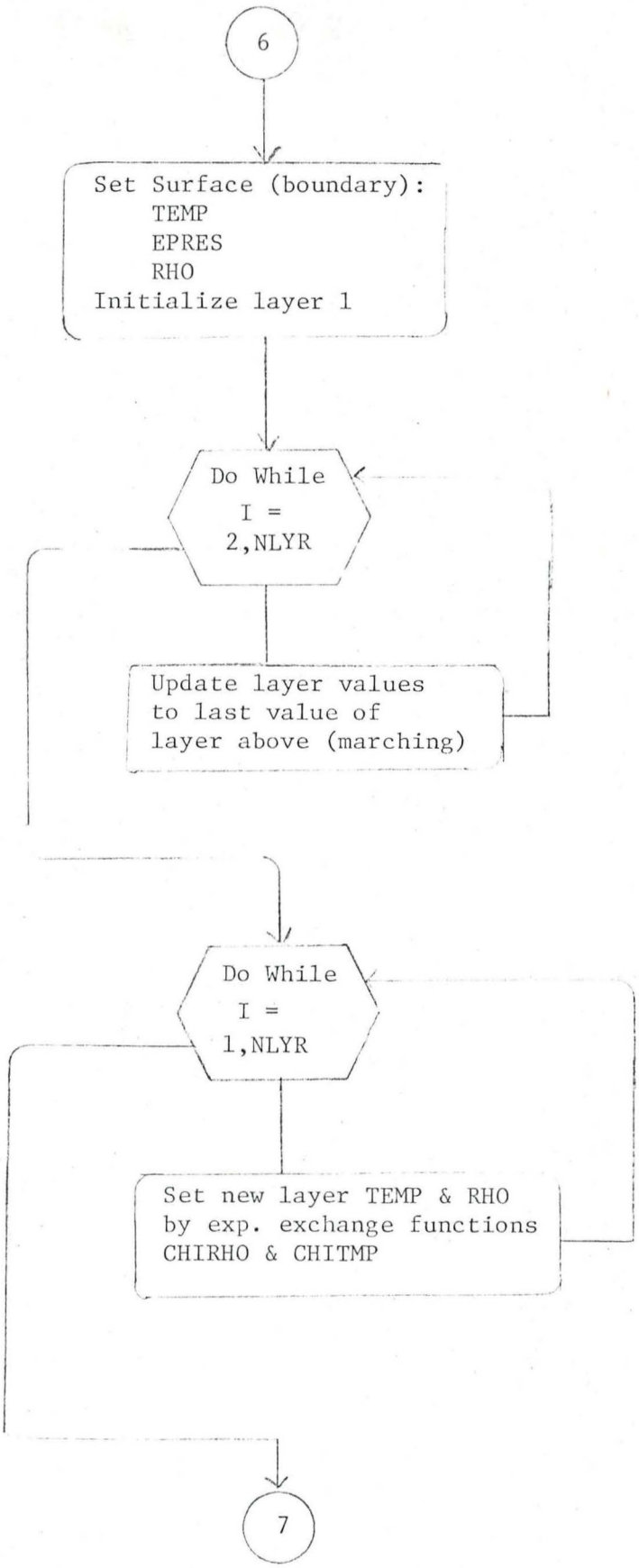
Narrative: This subroutine computes the saturation vapor pressure given the temperature in degrees K from the Smithsonian table. The routine is from the NFDRS and the pressure is returned in dynes/cm^2.

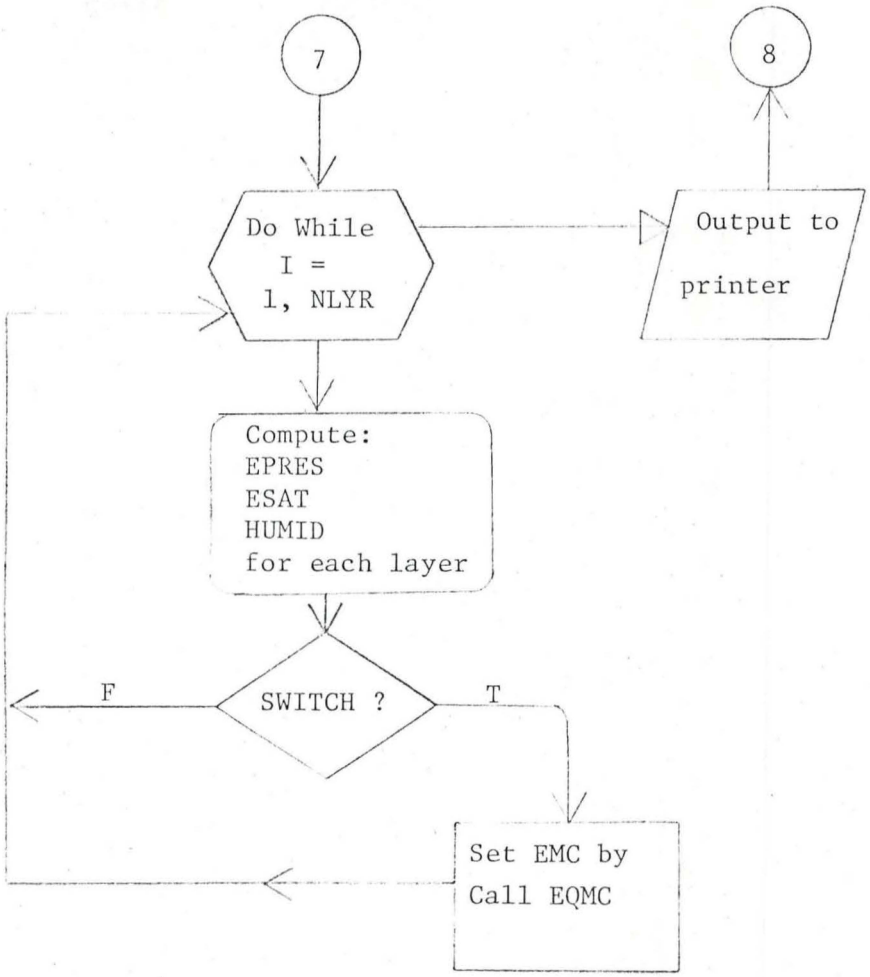
PROGRAM DUFF

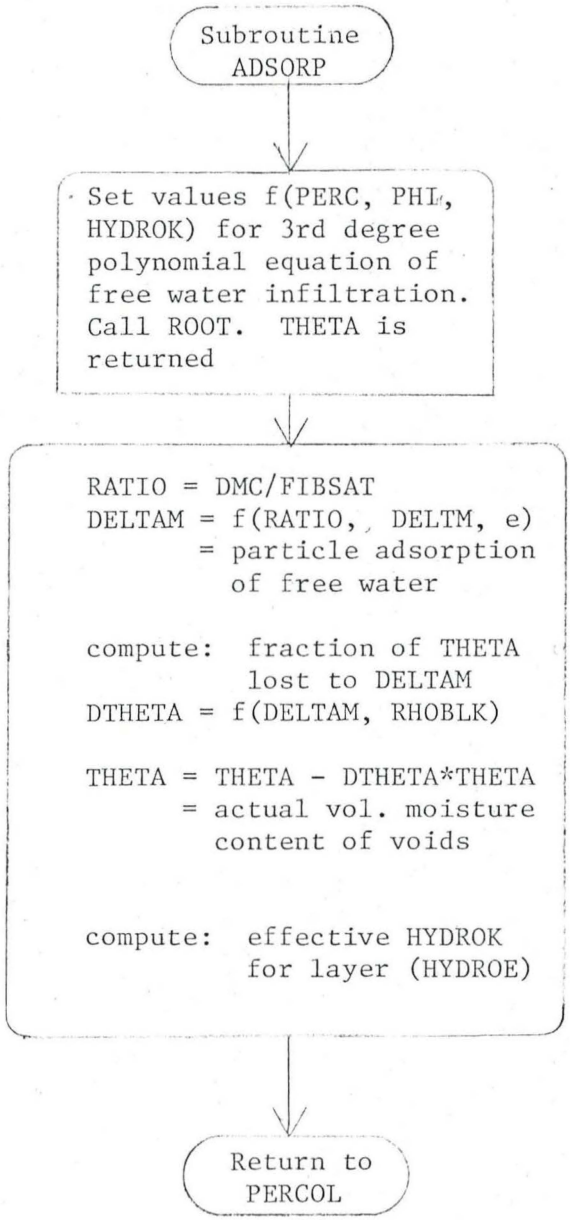


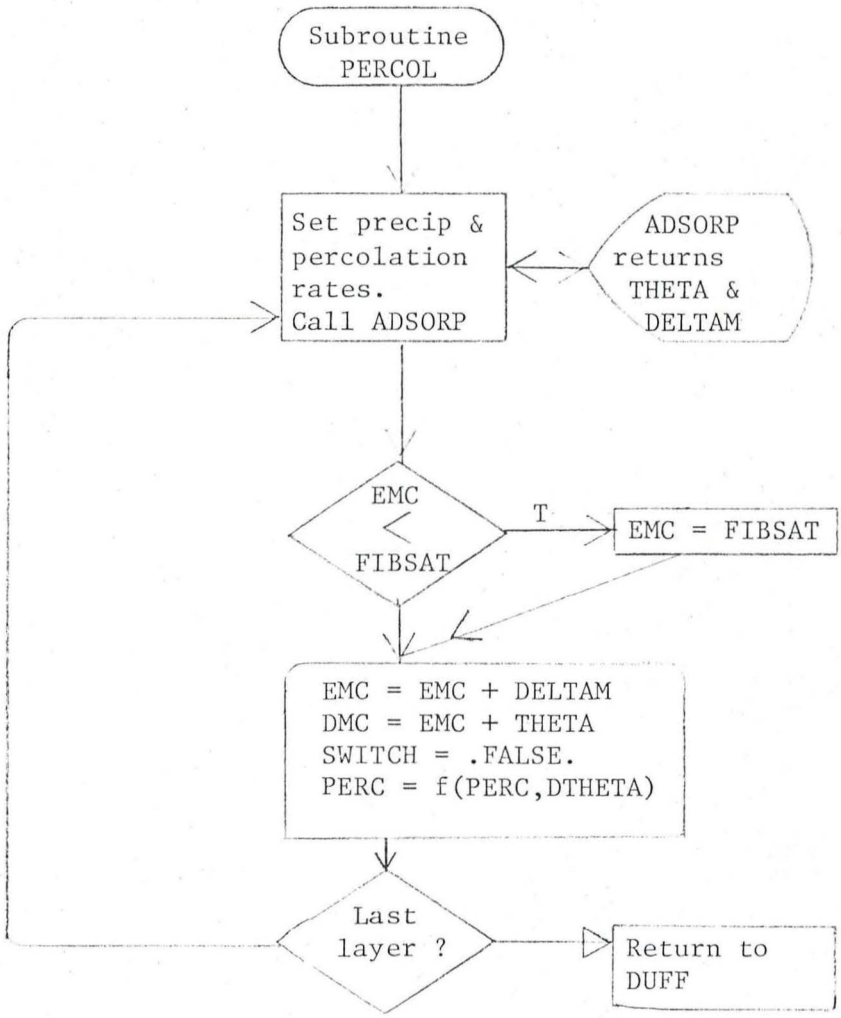

3
2
1
4
compute BETA
Solve: Eq. 12, P. 6
Eq. 11a & 11b, P. 6
compute DEPTH
compute bed timelags:
Eq. 30 & 31, P. 14
Eq. 28 & 29, P. 9
compute exponential exchange
functiions:
Eq. 24, P. 8
Bed Characteristics
to printer
Initialize
Layers
CALL PROFL1
5
4

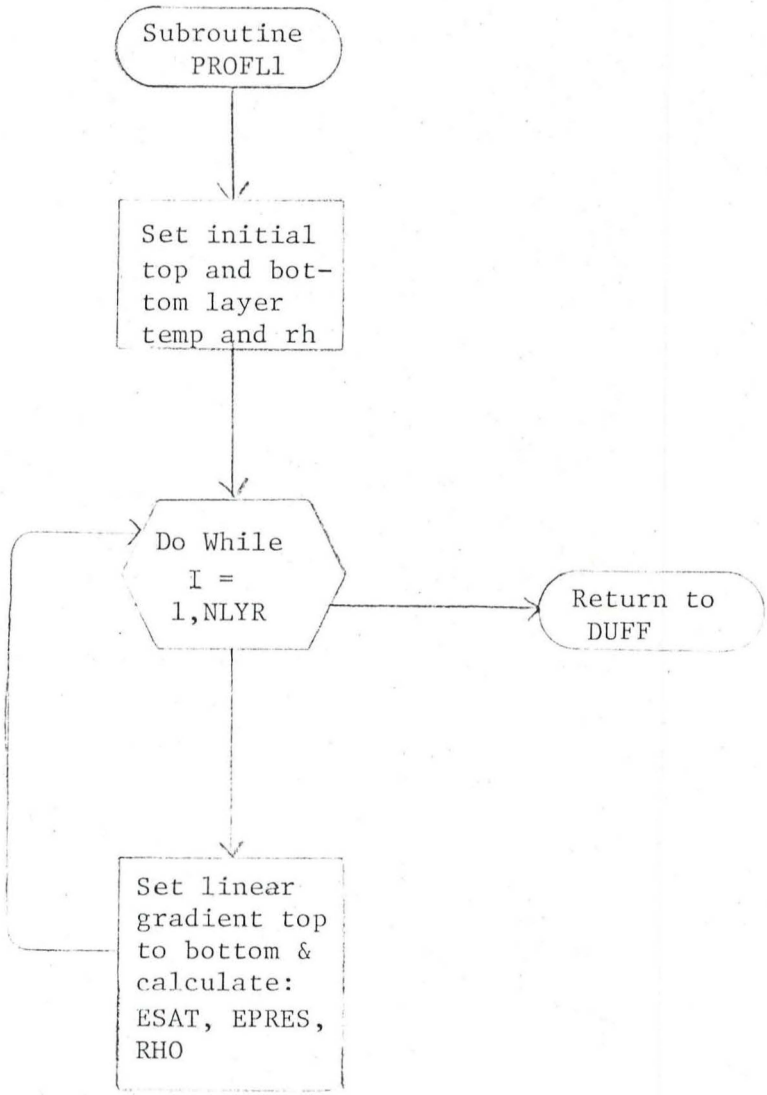

5
4
Do While
ITIME =
1,PRTSTP
Do While
KTIME =
1,SKPSTP
8
Read weather
observation
N
Rain ?
Y
Call PERCOL
Do While
I =
1,NLYR
RATIO = FIBSAT/DMC
DELTAM = f(e,RATIO,DELTM)
DTHETA = f(DELTAM,RHOBLK)
EMC = last EMC - DELTAM
DMC = new EMC - DTHETA
SWITCH = .FALSE.
N
DMC
>
FIBSAT
Y
DTHETA = 0.
THETA = 0.
DELTAM = 0.
SWITCH = .T.
6


6
Set Surface (boundary):
TEMP
EPRES
RHO
Initialize layer 1
Do While
I =
2,NLYR
Update layer values
to last value of
layer above (marching)
Do While
I =
1,NLYR
Set new layer TEMP & RHO
by exp. exchange functions
CHIRHO & CHITMP
7

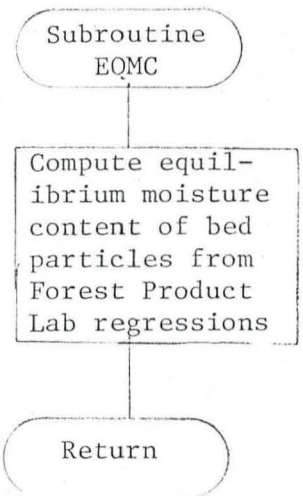

7
8
Do While
I =
1, NLYR
Output to
printer
Compute:
EPRES
ESAT
HUMID
for each layer
F
SWITCH ?
T
Set EMC by
Call EQMC


Subroutine ADSORP
Set values f(PERC, PHL, HYDROK) for 3rd degree polynomial equation of free water infiltration. Call ROOT. THETA is returned
RATIO = DMC/FIBSAT
DELTAM = f(RATIO, DELTM, e)
= particle adsorption of free water
compute: fraction of THETA lost to DELTAM
DTHETA = f(DELTAM, RHOBLK)
THETA = THETA - DTHETA*THETA
= actual vol. moisture content of voids
compute: effective HYDROK for layer (HYDROE)
Return to PERCOL


Subroutine
PERCOL
Set precip &
percolation
rates.
Call ADSORP
ADSORP
returns
THETA &
DELTAM
EMC
<
FIBSAT
T
EMC = FIBSAT
EMC = EMC + DELTAM
DMC = EMC + THETA
SWITCH = .FALSE.
PERC = f(PERC,DTHETA)
Last
layer ?
Return to
DUFF


Subroutine PROFL1
Set initial top and bottom layer temp and rh
Do While I = 1,NLYR
Return to DUFF
Set linear gradient top to bottom & calculate: ESAT, EPRES, RHO

Subroutine VAPOR
Compute sat. vapor pressure (ESAT) from Smithsonian Table
Return


Subroutine EQMC
Compute equilibrium moisture content of bed particles from Forest Product Lab regressions
Return

USDA FOREST SERVICE
INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
NORTHERN FOREST FIRE LABORATORY
Missoula, Montana

STUDY PLAN 2103-79-14
STUDY PLAN 2108-79-44

MOISTURE AND TEMPERATURE PROFILE VALIDATION OF FOSBERG MODEL PREDICTION

Fire Fundamentals Research Work Unit FS-INT-2103
Fire in Multiple Use Research Work Unit FS-INT-2108

Prepared by: William H. Frandsen — 7/13/79
William H. Frandsen, Research Physicist — Date

William C. Fischer — 7/13/79
William C. Fischer, Research Forester — Date

Approved by: R. C. Rothermel — 7/13/79
Richard C. Rothermel, Project Leader — Date

James E. Lotan, Program Manager — Date

Dr. Ralph A. Klawitter — Date
Assistant Director

TABLE OF CONTENTS

1. Problem Reference. 1

2. Literature 1

3. Objectives 2

4. Method. 2

Temperature Profile. 3

Moisture Content. 3

Weather 3

Duff Thermal and Physical Parameters. 4

Analysis. 4

5. Application. 5

6. Safety and Health. 6

7. Personnel Assignment. 6

8. Cooperation. 6

9. Costs. 7

10. References. 8

1. PROBLEM REFERENCE

This study refers to Problem No. 1 of the Fire Behavior Research work unit, RWU 2103. The problem is stated as follows: "How can the fundamental combustion process be described in terms of fuel parameters and expected meteorological conditions that will enable systems to be developed that will predict the expected size and intensity of a fire and the fire characteristics needed for evaluating fire effects?"

The absorption and desorption of moisture by forest fuels in response to the environment is the focal point of this study. It applies to the stated problem because the moisture content:

(a) is a fundamental parameter relating to combustion,
(b) is derived from meteorological conditions, and
(c) is necessary for evaluating fire effects.

The forest fuel referred to is the organic mantel covering the forest floor. The moisture content is expressed as a profile - function of the depth. The temperature profile is of secondary importance in this study. It is coupled to the moisture content and is included for completeness.

2. LITERATURE

Norum (1977) describes a technique for judging the amount of mineral soil exposed (by percent area) in slash fires from a knowledge of the duff moisture profile. Use of the technique requires periodically sampling the duff moisture until a profile is obtained that indicates that a fire would expose the amount of mineral soil desired by the fire management officer. The ability to predict duff moisture from weather patterns would allow the fire management officer to monitor more areas in less time and reduce travel. Such a model exists but has not been satisfactorily field checked.

Fosberg (1975) presented a theoretical model of the flow of heat and moisture vapor through absorbing (or desorbing) layers of forest duff and humus. This model suggests the feasibility of predicting day to day changes in the duff-humus moisture and temperature profile resulting from changes in the ambient temperature and humidity.

Fosberg described the transfer of heat and water vapor as an exchange between the void space and particles within the duff-humus layer. As the heat and moisture vapor diffuse into and from the duff-humus layer through the surface the particles respond by changes in their temperature and moisture content resulting in a time varying vertical moisture gradient. A later modification allows for changes in the gradient due to precipitation by accounting for the flow and retention of liquid water.

Bradshaw and Bevins* in discussion with Fosberg used these concepts in a computer model called "Duff". It has been validated to a limited degree to show that it operates in a reasonable manner.

The variables used to drive the model are ambient temperature and humidity at the ground level and precipitation by amount and duration. Coefficients describing the heat, moisture vapor, and liquid water transfer are also necessary and must be derived by separate means and vary from site to site. The latter may be looked upon as adjustable site parameters.

3. OBJECTIVES

The primary purpose of this study is to calibrate the "Duff" computer model with field data for specific sites and by so doing, examine the validity of the model. Calibration consists of exercising the Fosberg Model by adjusting the heat and mass transfer coefficients of the model and utilizing the independent parameters; temperature, humidity, and precipitation to obtain predictions of the moisture and temperature profile for comparison with observation.

The secondary purpose is to acquire sufficient information to either modify the present model or generate a model. The latter, however, will be more difficult because of limited data. We presently anticipate the power of employing a deterministic model and thus do not need the large amounts of data required by stochastic models. In any case, if the model fails we will have the beginnings of a stochastic model.

Norum presents graphical information suggesting that moisture content varies $\pm$ 40% about the mean for a given percent duff reduction. This variance reflects the variable nature of the moisture content over the area measured - in this case, slash areas. Accepting this variance as a site characteristic indicates that our examination on smaller areas should result in variances less than 40%.

There is not adequate space in this study plan to examine the variance limits necessary to supply the land manager with the accuracy required to make quality land management decisions. For instance, how much variance in duff reduction can the land manager tolerate in exposing mineral soil for vegetative regeneration? How does it vary from site to site? Answers to these questions would allow us to set reasonable limits on an acceptable moisture variance.

4. METHOD

Four sites have been located (Figure 1) in a drainage west of Missoula, following the Elk Meadow Road. Two sites, one at the bottom (4100 ft) and the other at the top (6300 ft), are generally wetter than the other two intermediate sites. Our motive is to examine the model at both wet and dry conditions.

*Personal Communication

Temperature and humidity recording equipment (hygrothermograph) will be placed in shelters at ground level adjacent to the sampling area. A precipitation recording rain gauge will also be placed adjacent to the sampling area. Four other ordinary (non-recording) rain gauges will be placed on each side of the sampling area to obtain information about the variance in the amount of rain falling on the sampling site.

A 10 ft by 10 ft grid will be located at each site. A random sampling of 20 duff depths (organic mantle down to mineral soil) will be obtained adjacent to the grid network of each site. The frequency distribution of the depth will be used to determine the number of samples taken from each site. The wider the distribution the more samples will be taken.

Each sample will be taken from one grid square on the basis of the selection of a random number between 0 and 99. A random two digit number can be easily obtained from a random number table. The first digit is the row and the second the column of the field grid. Repeat selection when random numbers are duplicated.

Temperature Profile

A temperature profile will be obtained from each sampled grid location prior to removing the duff samples. The profile will be measured by inserting a thermocouple probe down into the duff at 1 cm intervals from the surface to mineral soil.

Moisture Content

All live vegetation will be clipped from each site - including a two foot perimeter - to eliminate evapotranspiration from the site. Duff moisture samples will be taken at each weather station and the six additional sampling sites located in each drainage. A sample consists of 3/4 of a "can" of upper duff and 3/4 of a "can" of lower duff. A "can" is a cylinder, 4 inches in diameter and 2.5 inches deep. Upper duff is defined as the undecomposed loose litter on the surface that can still be distinguished as leaves and twigs. The lower duff is a consolidated mat of partially decomposed organic material. Be sure that mineral soil is absent from the lower duff sample.

Each sample will be sealed with plastic electrician's tape and weighed with tape removed at the fuels lab prior to oven drying. Drying will be accomplished by placing the can in an oven for 24 hrs. at 105°C. After removal from the oven the dry fuel and can are weighed. Finally, the can is weighed separately. The percent moisture content relative to the dry weight is:

$$\%M.C. = [(B-C)/C-A]x100$$

where A = Can Weight
B = Moist fuel and can weight
C = Dry fuel and can weight

Records will be kept of the moisture content by drainage, site, random number selected, date, and observer.

Each site will be sampled twice a week (Monday and Thursday). A schedule will be maintained so that each site is measured between the hours of 11:00 and 3:00 p.m. In addition to the weekly visits each site will be monitored for duff moisture and temperature over a 24 hour period at 2 hour intervals by stationing an individual at the site. The 2 hour interval was selected because it lies within the time required for the duff to respond to changes in humidity. We will anticipate measuring these sites within 2 to 4 hours after precipitation, in order to follow wetting and drying at high moisture levels.

Weather

The following measurements will be made at each site location when duff samples are taken:

(a) wet and dry bulb temperatures.
(b) water content of rain gauges.

Records of the hygrothermograph, precipitation, and wind will be maintained for validating model predictions against recorded duff moisture profiles (moisture content vs. depth).

Duff Thermal and Physical Parameters

Techniques will be devised to determine the thermal diffusivity, vapour diffusivity, and hydraulic conductivity of the duff on each site. Bulk and particle densities will also be determined to complete the requirements of the Fosberg model.

Duff samples (1 ft x 1 ft) will be taken intact from each site and measured at different moisture values under laboratory conditions to determine the dependendence of thermal diffusivity on moisture. Duff samples normally include only the organic mantle, but may include some mineral soil if convenient.

Analysis

Beginning with the initial moisture and temperature profile, the duff computer model (Fosberg model) will update the profiles based upon changes in the above-ground temperature, humidity, and precipitation. Modeling parameters (heat and mass transfer coefficients) are intended to account for site differences. Site specific reasonable adjustments; i.e., calibrations, will be made to bring predictions in line with observations.

5. APPLICATION

Results of this study will lead to methods that will allow the user to estimate duff moisture content from weather measurements rather than gathering on site moisture samples of the organic mantle. This will result in a savings of both time and travel costs. specifically for remote sites and assessing large areas. This also points to the possibility of forecasting duff moisture contents from weather forecasts, an advantage to planning prescribed burns.

This study offers the opportunity to examine the fundamental process of moisture and heat transfer in the organic mantel. It sets the stage for other studies examining moisture and heat transfer to sub-surface biological systems during the spread of surface fires rather than diurnal fluctuations in the weather as discussed here.

6. SAFETY AND HEALTH

Field personnel will review the 1979 Fire in Multiple Use RD&A Safety Plan* prior to starting work on this study. The RD&A field safety officer will conduct a hazard survey of the study sites and the proposed field work. The results of this survey will be reported to study participants and any necessary corrective action will be completed before field work begins.

7. PERSONNEL ASSIGNMENT

ITEM	ASSIGNMENT	RESPONSIBILITY
Study site location	Bill Frandsen John Roberts Larry Bradshaw	Frandsen
Placement of weather stations	Pat Hartless	Fischer
Data Collection	John Barlow	Fischer
Hazard Analysis	Pat Hartless	Fischer
Data Analysis	Larry Bradshaw Bill Frandsen	Frandsen
Reporting	Larry Bradshaw Bill Frandsen	Frandsen
Publication of Results	Larry Bradshaw Bill Frandsen Bill Fischer	Fischer

8. COOPERATION

This is a joint study between INT-RWU 2103 and 2108. A third cooperator: Systems for Enviornmental Management (SEM), is provided for by cooperative agreement (Supplement No. 6 to Master Memorandum effective 8/2/77) between SEM and RWU 2108. The study sites are located on the Missoula Ranger District, Lolo N.F. Missoula District personnel participated in study site selection.

*Hartless, Patrick F. Safety Plan, 1979. Fire in Multiple Use Research Development and Applications Program, Northern Forest Fire Laboratory.

9. COSTS

Field assistant		1,800.00
Travel		400.00
Computer costs		2,000.00
SEM reimbursement		11,195.00
SEM contribution		1,450.00
RWU 2108 permanent personnel		1,000.00
RWU 2103 permanent personnel		1,500.00
	TOTAL COST	$19,345.00

10. REFERENCES

Norum, Rodney A.
1977. Preliminary guidelines for prescribed burning under standing timber in Western Larch/Douglas-fir forests. Res. Note INT-229.

Fosberg, Michael.
1975. Heat and Water Vapor Flux in Conifer Forest Litter and Duff: A theoretical model. Res. Paper RM-152.

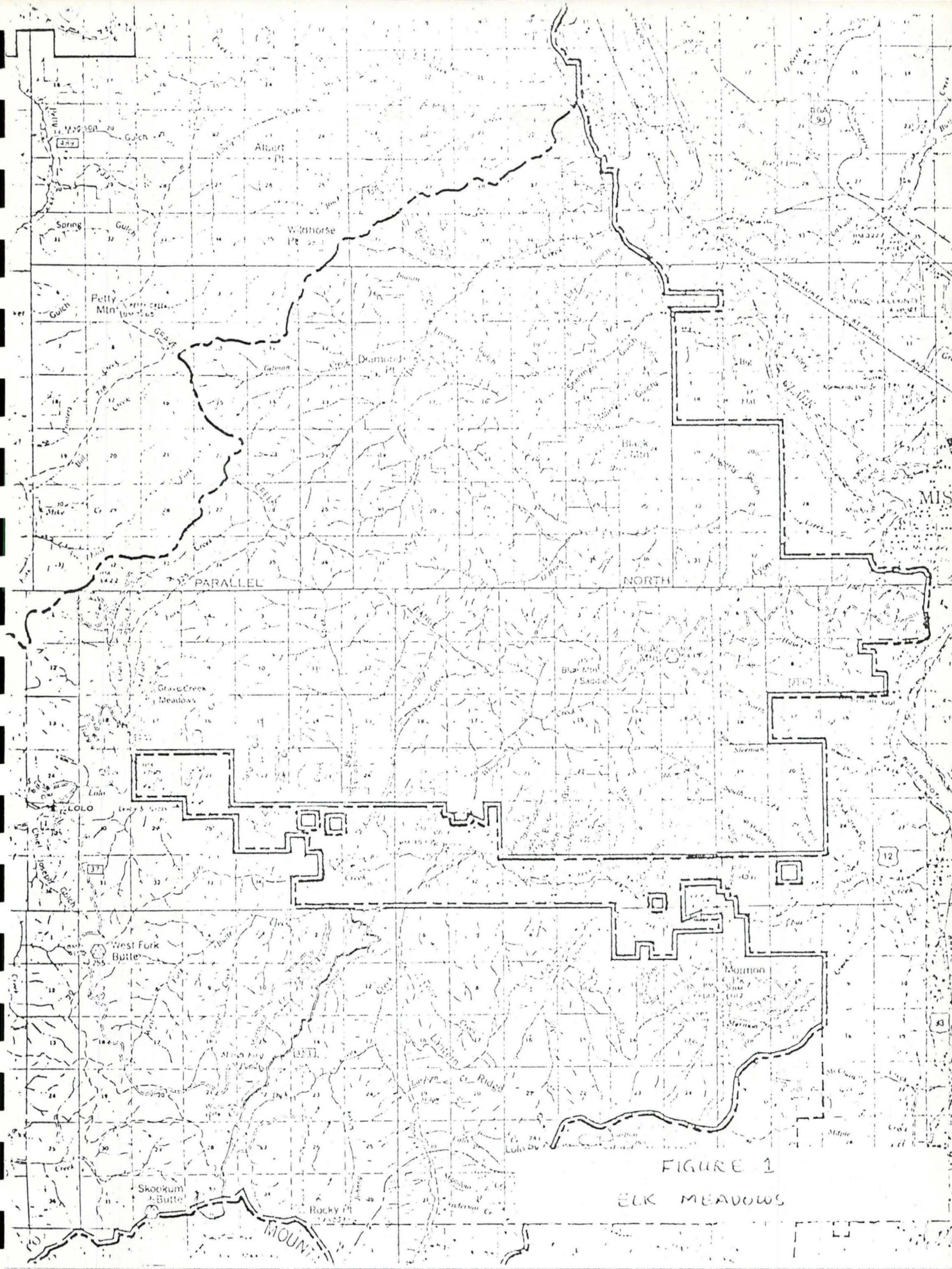


FIGURE 1

ELK MEADOWS